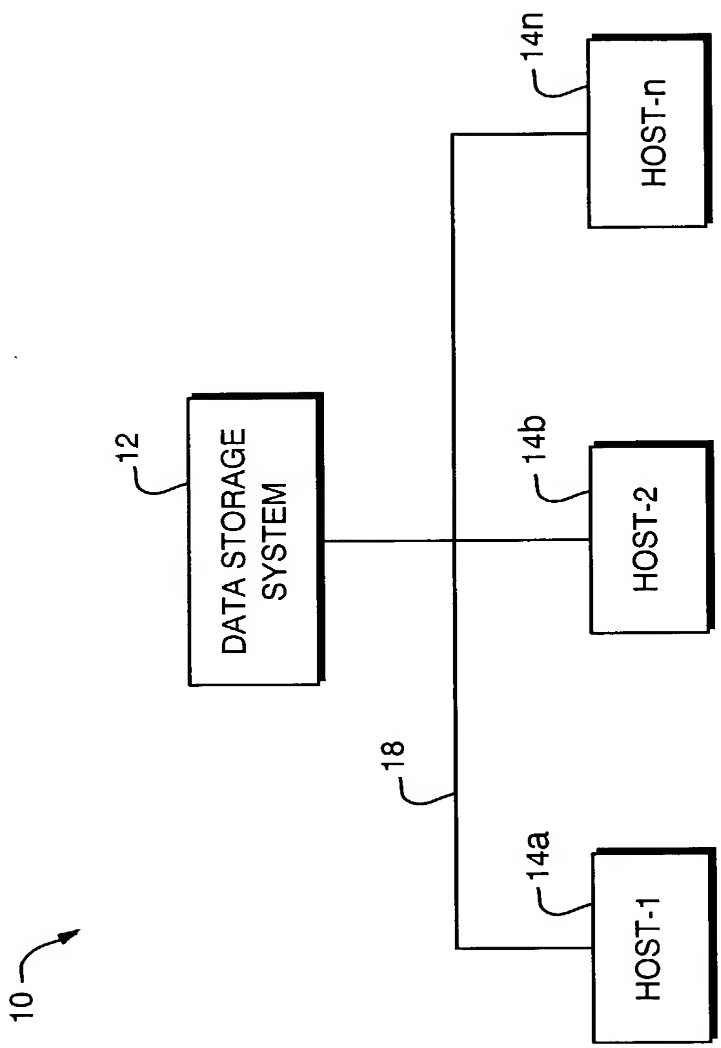


FIG. 1

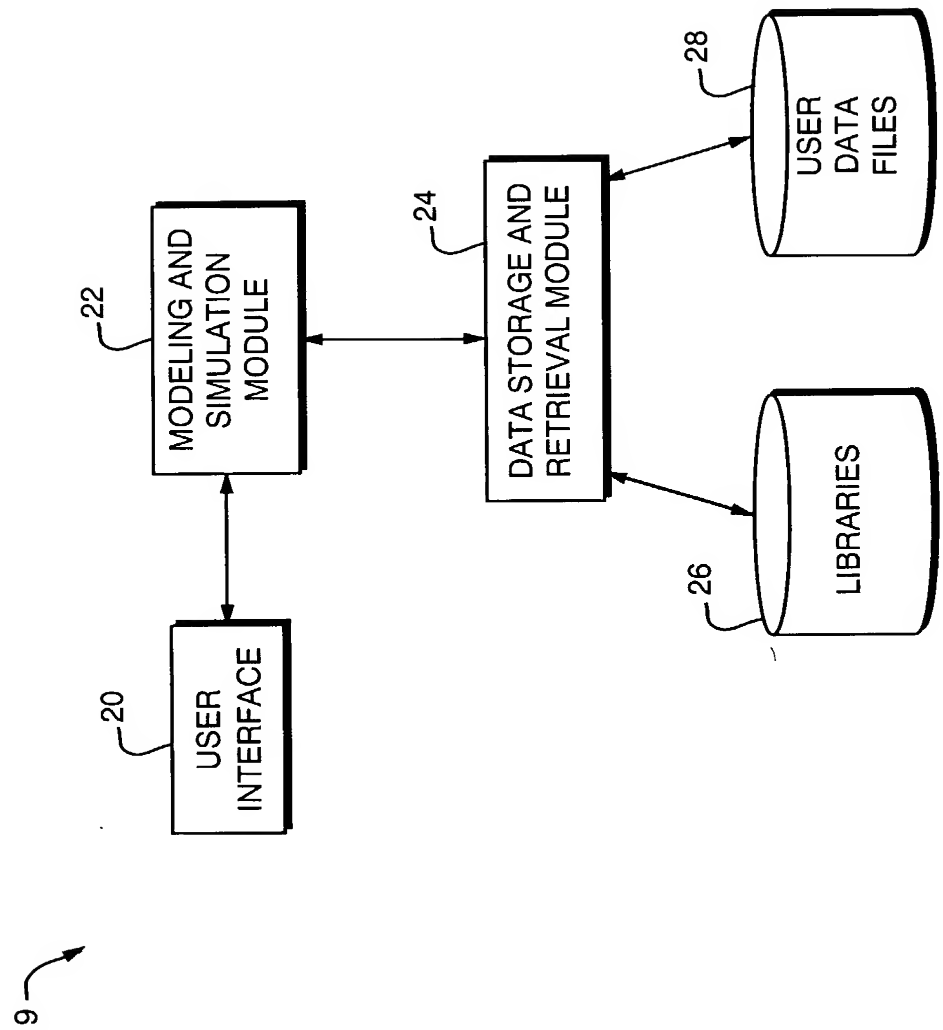

19
20
USER INTERFACE
22
MODELING AND SIMULATION MODULE
24
DATA STORAGE AND RETRIEVAL MODULE
26
LIBRARIES
28
USER DATA FILES

FIG. 2

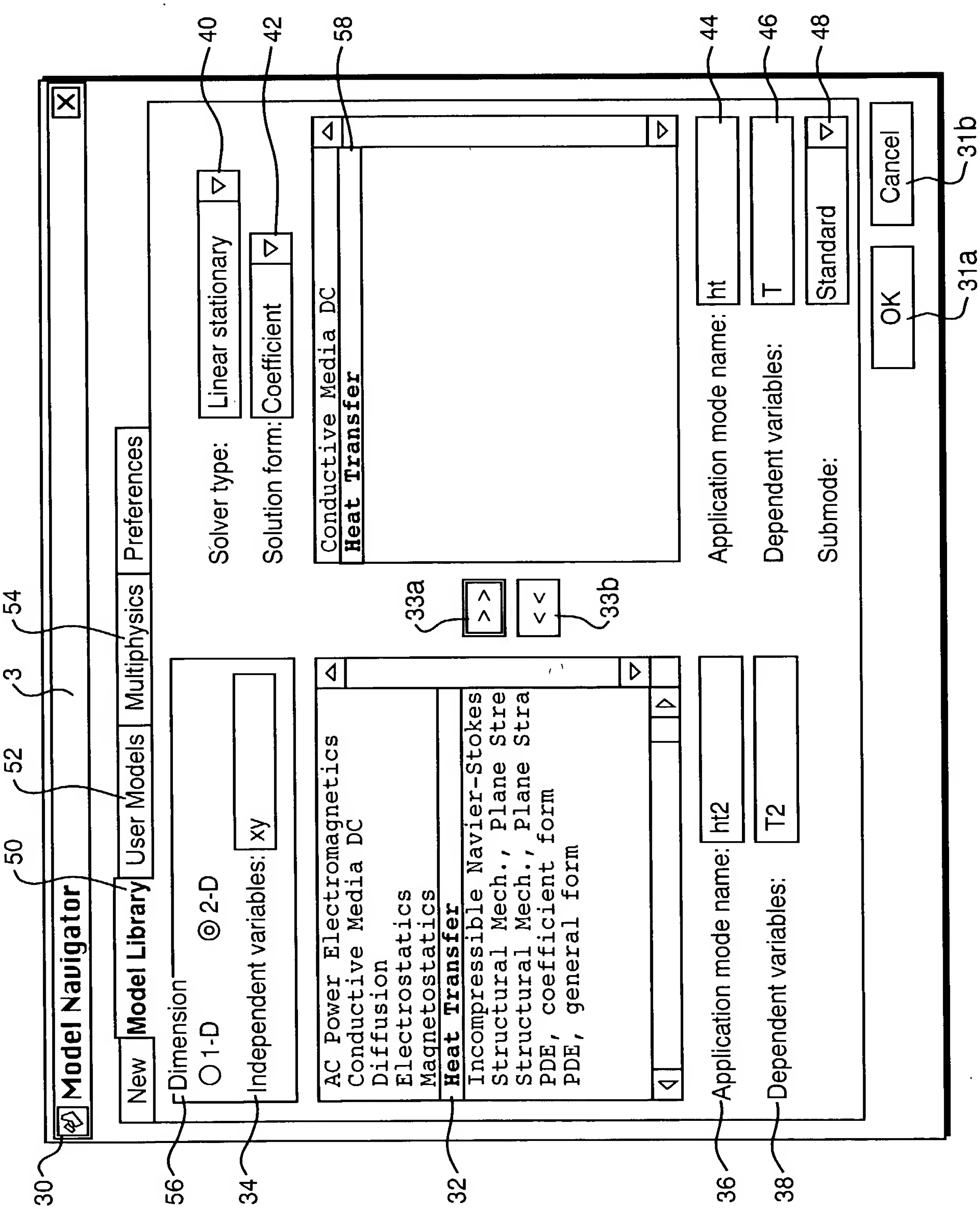

Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Dimension
1-D
2-D
Independent variables:
xy
AC Power Electromagnetics
Conductive Media DC
Diffusion
Electrostatics
Magnetostatics
Heat Transfer
Incompressible Navier-Stokes
Structural Mech., Plane Stre
Structural Mech., Plane Stra
PDE, coefficient form
PDE, general form
Application mode name:
ht2
Dependent variables:
T2
>>
<<
Solver type:
Linear stationary
Solution form:
Coefficient
Conductive Media DC
Heat Transfer
Application mode name:
ht
Dependent variables:
T
Submode:
Standard
OK
Cancel
30
56
34
32
36
38
50
52
3
54
33a
33b
40
42
58
44
46
48
31a
31b

FIG. 3

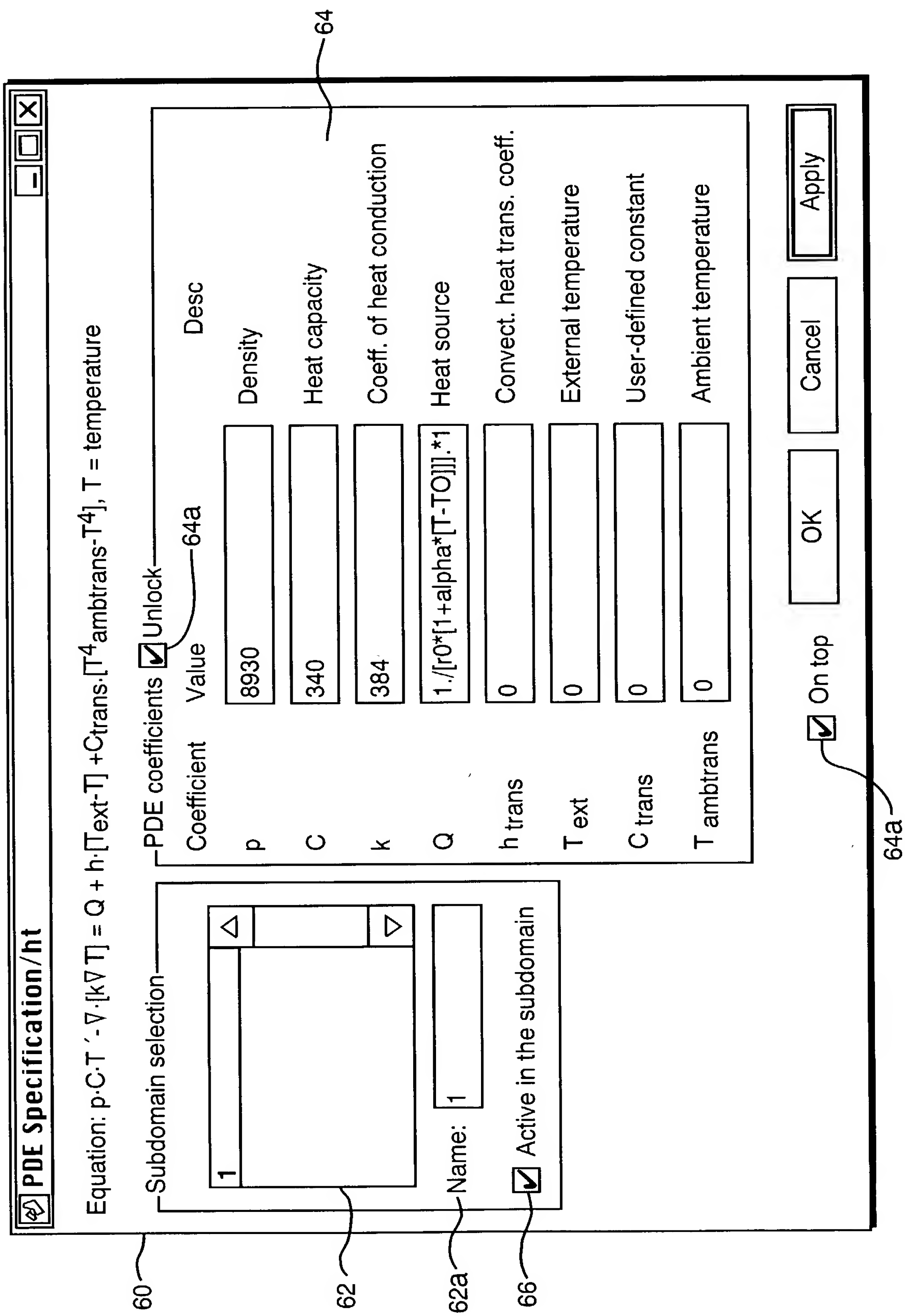

PDE Specification/ht
Equation: p·C·T ′ - ∇·[k∇T] = Q + h·[Text-T] +Ctrans·[T4ambtrans-T4], T = temperature
Subdomain selection
1
Name:
1
Active in the subdomain
PDE coefficients
Unlock
Coefficient
Value
Desc
p
8930
Density
C
340
Heat capacity
k
384
Coeff. of heat conduction
Q
1./[r0*[1+alpha*[T-TO]]].*1
Heat source
h trans
0
Convect. heat trans. coeff.
T ext
0
External temperature
C trans
0
User-defined constant
T ambtrans
0
Ambient temperature
On top
OK
Cancel
Apply
60
62
62a
66
64
64a
64a

FIG. 4

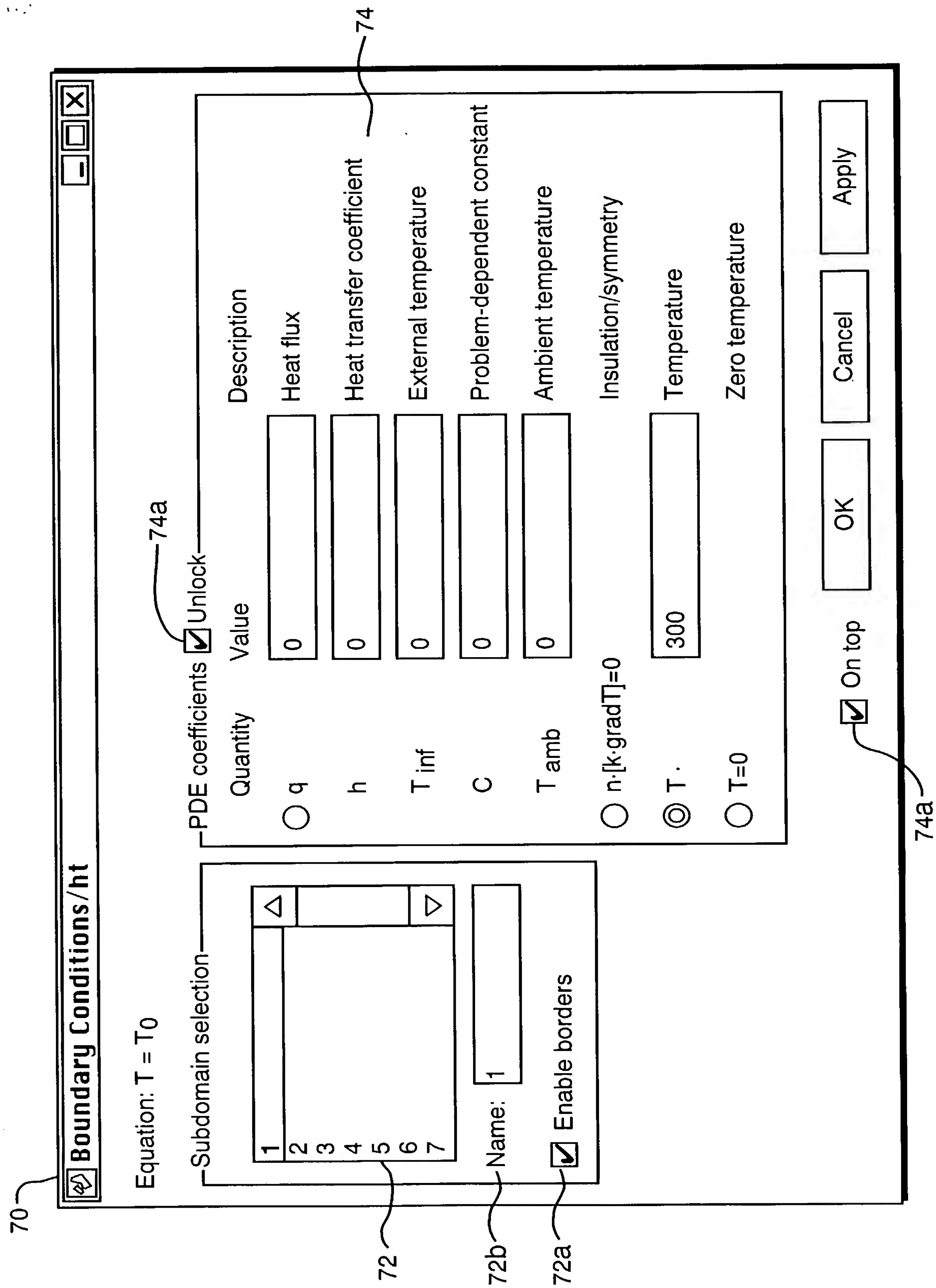

Boundary Conditions/ht
Equation: $T = T_0$
Subdomain selection
1
2
3
4
5
6
7
Name: 1
Enable borders
PDE coefficients
Unlock
Quantity
Value
Description
q
0
Heat flux
h
0
Heat transfer coefficient
T inf
0
External temperature
C
0
Problem-dependent constant
T amb
0
Ambient temperature
n·[k·gradT]=0
Insulation/symmetry
T
300
Temperature
T=0
Zero temperature
On top
OK
Cancel
Apply
70
72
72a
72b
74
74a

FIG. 5

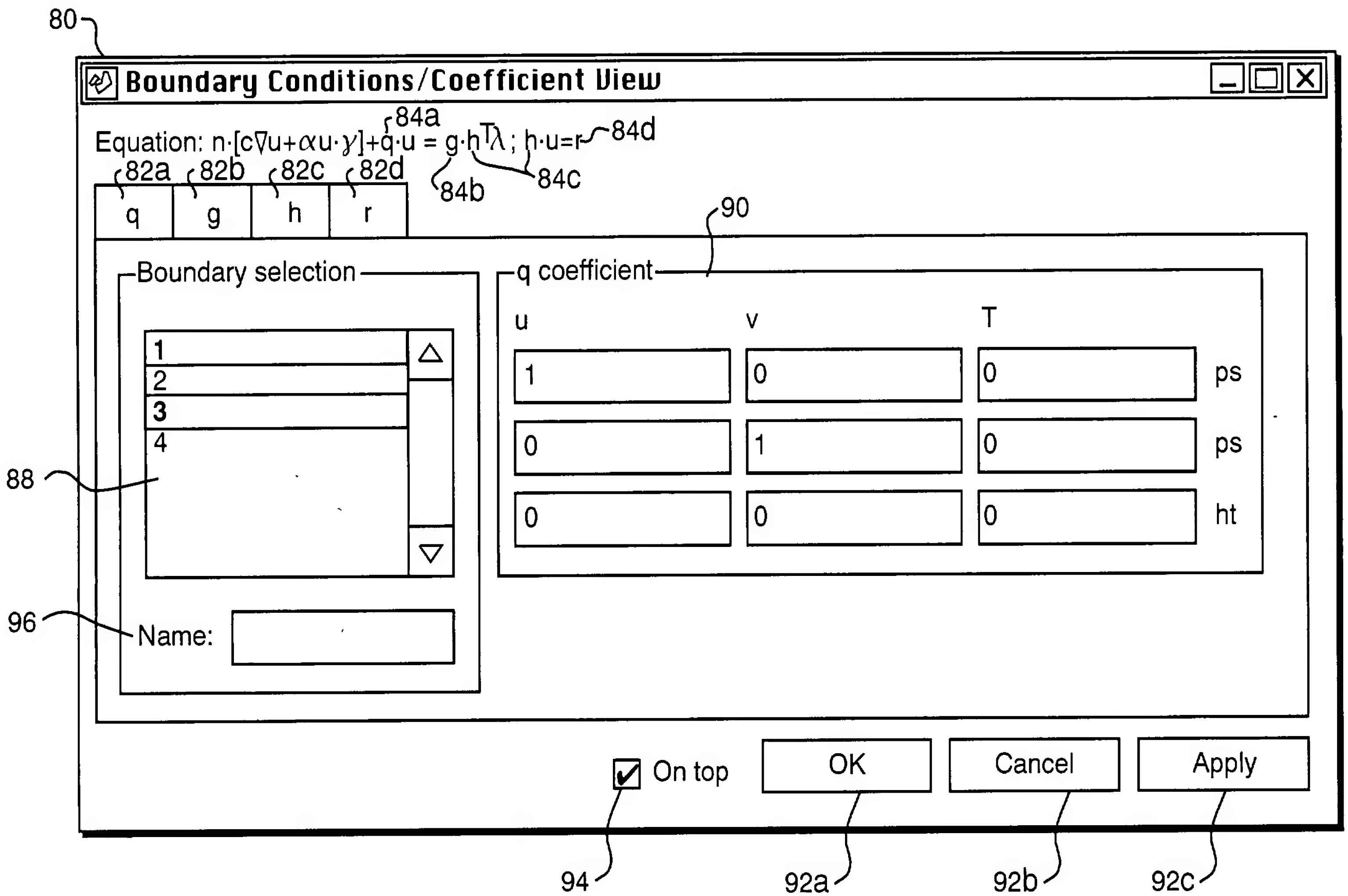

80
Boundary Conditions/Coefficient View
Equation: n·[c∇u+αu·γ]+q·u = g·hᵀλ ; h·u=r
84a
84d
84b
84c
82a
82b
82c
82d
q
g
h
r
90
Boundary selection
q coefficient
u
v
T
1
2
3
4
1 0 0 ps
0 1 0 ps
0 0 0 ht
88
96
Name:
On top
OK
Cancel
Apply
94
92a
92b
92c

FIG. 6

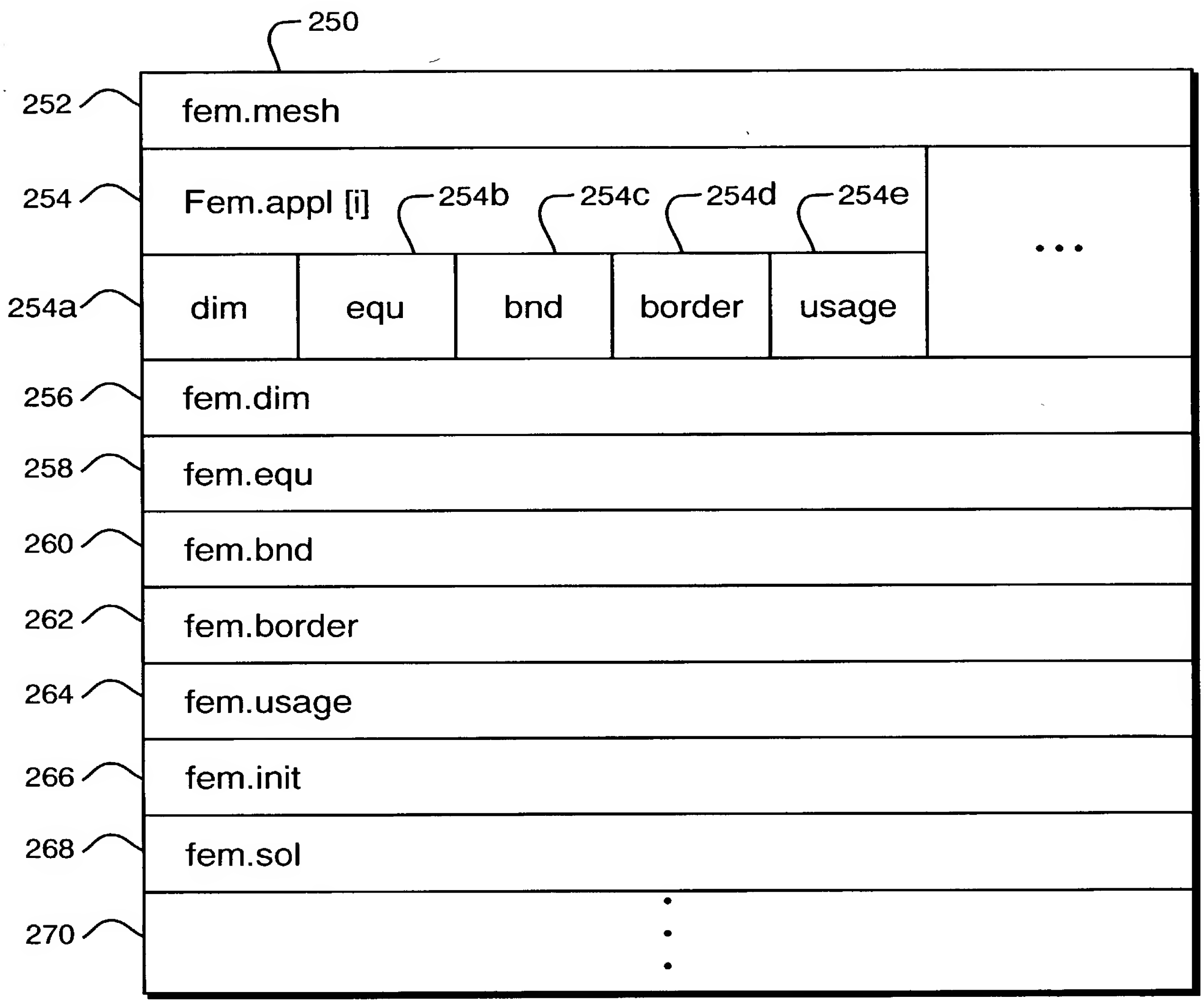

250
252
fem.mesh
254
Fem.appl [i]
254b
254c
254d
254e
...
254a
dim
equ
bnd
border
usage
256
fem.dim
258
fem.equ
260
fem.bnd
262
fem.border
264
fem.usage
266
fem.init
268
fem.sol
270

FIG. 6A

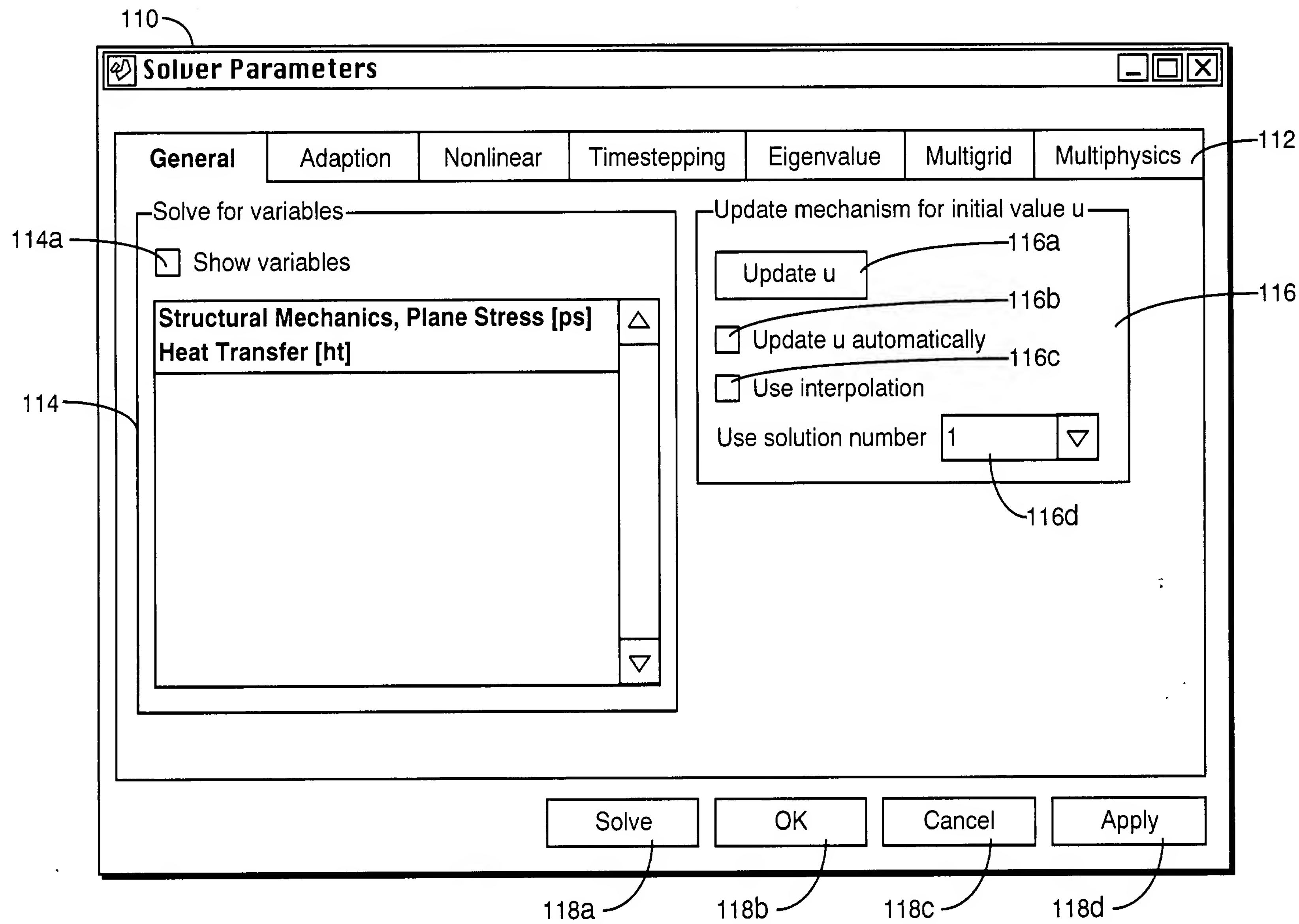

110
Solver Parameters
General
Adaption
Nonlinear
Timestepping
Eigenvalue
Multigrid
Multiphysics
112
Solve for variables
114a
Show variables
Structural Mechanics, Plane Stress [ps]
Heat Transfer [ht]
114
Update mechanism for initial value u
Update u
116a
116b
Update u automatically
116c
Use interpolation
116
Use solution number
1
116d
Solve
OK
Cancel
Apply
118a
118b
118c
118d

FIG. 7

$$140\left\{\begin{array}{ll} d_{a\,lk}\frac{\partial u_k}{\partial t} - \frac{\partial}{\partial x_j}\left(c_{lkji}\frac{\partial u_k}{\partial x_i} + \alpha_{lkj}u_k - \gamma_{lj}\right) + \beta_{lki}\frac{\partial u_k}{\partial x_i} + a_{lk}u_k = f_i & \left.\Omega\right\rangle 142 \\ n_j\left(c_{lkji}\frac{\partial u_k}{\partial x_i} + \alpha_{lkj}u_k - \gamma_{lj}\right) + q_{lk}u_k = g_l - h_{ml}\lambda_m & \left.\partial\Omega\right\rangle 146a \\ h_{ml}u_l = r_m & \left.\partial\Omega\right\rangle 146b \end{array}\right.$$

146

FIG. 8

$$150\left\{\begin{array}{ll} d_{a\,lk}\frac{\partial u_k}{\partial t} + \frac{\partial \Gamma_{lj}}{\partial x_j} = F_l & \left.\Omega\right\rangle 152 \\ \sim n_j\Gamma_{lj} = G_l + \frac{\partial R_m}{\partial u_l}\lambda_m & \left.\partial\Omega\right\rangle 154a \\ O = R_m & \left.\partial\Omega\right\rangle 154b \end{array}\right.$$

154

FIG. 9

$$324\left\{\begin{array}{ll}
\gamma_{lj} = \Gamma_{lj} & f_l = F_l \\[2ex]
c_{lkji} = -\dfrac{\partial \Gamma_{lj}}{\partial\left(\dfrac{\partial n_k}{\partial x_i}\right)} & \alpha_{lkj} = -\dfrac{\partial \Gamma_{lj}}{\partial u_k} \\[2ex]
\beta_{lki} = -\dfrac{\partial F_l}{\partial\left(\dfrac{\partial m_k}{\partial x_i}\right)} & a_{lk} = -\dfrac{\partial F_l}{\partial u_k} \\[2ex]
g_l = G_l & r_l = R_l \\[2ex]
q_{lk} = -\dfrac{\partial G_l}{\partial u_k} & h_{lk} = -\dfrac{\partial R_l}{\partial u_k}
\end{array}\right.$$

FIG. 10

$$240\left\{\begin{aligned}
\Gamma_{lj} &= -c_{lkji}\frac{\partial u_k}{\partial x_l} - \alpha_{lkj}u_k + \gamma_{lj}\\
F_l &= f_l - \beta_{lki}\frac{\partial u_k}{\partial x_i} - a_{lk}u_k\\
G_l &= g_l - q_{lk}u_k\\
R_m &= r_m - h_{ml}u_l
\end{aligned}\right.$$

FIG. 11

$$
300 \left\{
\begin{array}{l}
\int_{\Omega} \left(\left(c_{lkji} \frac{\partial u_k}{\partial x_i} \pm \alpha_{lkj} u_k \right) \frac{\partial v}{\partial x_j} + \left(d_{a\,lk} \frac{\partial u_k}{\partial l} + \beta_{lki} \frac{\partial u_k}{\partial x_i} + a_{lk} u_k \right) v \right) dx + \\[2ex]
\int_{\partial\Omega} q_{lk} u_k v\, ds = \int_{\Omega} \left(\gamma_{lj} \frac{\partial v}{\partial x_j} + f_l v \right) dx + \int_{\partial\Omega} (g_l - h_{ml} \lambda_m) v\, ds \\[2ex]
\int_{\partial\Omega} \mu h_{mk} u_k\, ds = \int_{\partial\Omega} \mu r_m\, ds
\end{array}
\right.
$$

FIG. 12

$$302\left\{\begin{aligned}&\int_{\Omega}\left(\Gamma_{lj}\frac{\partial v}{\partial x_j}+F_{lv}-d_{alk}\frac{\partial u_k}{\partial l}v\right)dx+\int_{\partial\Omega}+\left(G_l+\frac{\partial R_m}{\partial u_l}\lambda_m\right)vds=O\\&\int_{\partial\Omega}R_m\,\mu ds=O\end{aligned}\right.$$

FIG. 13

$$304 \left\{ U_k(x) = \sum_{I=1}^{N_p} U_{I.k} \Phi_I(x); \qquad \Lambda_m(x) = \sum_{k=1}^{N_c} \sum_{L=l}^{n} \Lambda_{K,L,m} \Psi_{K,L}(x) \right.$$

FIG. 14

$$
306\left\{
\begin{array}{l}
\int_t \left(c_{lkji}\, U_{I,k} \dfrac{\partial \Phi_I}{\partial x_i} + \alpha_{lkj}\, U_{I,k} \Phi_I \right) \dfrac{\partial \Phi_J}{\partial x_j}\, dx + \\[2ex]
\int_t \left(d_{a\,lk} \dfrac{\partial U_{I,k}}{\partial l}\, \Phi_I + \beta_{lki} U_{I,k} \dfrac{\partial \Phi_I}{\partial x_i} + a_{lk}\, U_{I,k} \Phi_I \right) \Phi_J\, dx + \\[2ex]
\int_{\partial t} q_{lk} U_{I,k} \Phi_I \Phi_j\, ds = \int_t \left(\gamma_{lj} \dfrac{\partial \Phi_J}{\partial x_j} + f_l \Phi_J \right) dx + \\[2ex]
\int_{\partial t} (g_l - h_{ml} \Lambda_{K,L,m} \Psi_{K,L})\, \Phi_J\, ds
\end{array}
\right.
$$

FIG. 15

$$308\left\{\begin{array}{l}\int h_{mk} U_{I,k} \Phi_I \Psi_{K,L}\, ds = \int r_m \Psi_{K,L}\, ds \\ \partial t\end{array}\right.$$

FIG. 16

$$312\;\left\{\begin{array}{l}\int_t\left(\Gamma_{lj}\dfrac{\partial\Phi_j}{\partial x_j}+F_l\Phi_j-d_{alk}\dfrac{\partial u_k}{\partial t}\Phi_J\right)dx+\int_{\partial t}+\left(G_l+\dfrac{\partial R_m}{\partial u_l}\Lambda_{K,L,m}\Psi_{K,L}\right)\Phi_J\,ds=O\\[2ex]\int_{\partial t}R_m\Psi_{K,L}\,ds=O\end{array}\right.$$

FIG. 17

310

$$DA_{(J,l),(I,k)} = \int_t d\ a\ {}_{lk}\Phi_I \Phi_J\, dx$$

$$C_{(J,l),(I,k)} = \int_t c_{lkji} \frac{\partial \Phi_I}{\partial x_i} ? \frac{\partial \Phi_J}{\partial x_j}\, dx$$

$$AL_{(J,l),(I,k)} = \int_t \alpha_{lkj} \Phi_I ? \frac{\partial \Phi_J}{\partial x_j}\, dx$$

$$BE_{(J,l),(I,k)} = \int_t \beta_{lki} \frac{\partial \Phi_I}{\partial x_i} \Phi_J\, dx$$

$$A_{(J,l),(I,k)} = \int_t a_{lk} \Phi_I \Phi_J\, dx$$

$$Q_{(J,l),(I,k)} = \int_{\partial t} q_{lk} \Phi_I \Phi_J\, ds$$

$$GA_{(J,l)} = \int_t \gamma_{lj} \frac{\partial \Phi_J}{\partial x_j}\, dx$$

$$F_{(J,l)} = \int_t f_l \Phi_J\, dx$$

$$G_{(J,l)} = \int_{\partial t} g_l \Phi_J\, ds$$

$$H_{(K,L,m),(I,k)} = \int_{\partial t} h_{mk} \Phi_I \Psi_{K,L}\, ds$$

$$R_{(K,L,m)} = \int_{\partial t} r_m \Psi_{K,L}\, ds$$

FIG. 18

$$320 \left\{ \begin{array}{l} DA \dfrac{\partial U}{\partial t} + (C+AL+BE+A+Q)\, U + H^T \Lambda = GA+F+G \\ HU=R \end{array} \right.$$

FIG. 19

$$322\left\{\begin{aligned} &DA\,\frac{\partial U}{\partial t}+H^T\Lambda = GA+F+G \\ &R=O \end{aligned}\right.$$

FIG. 20

$$326 \begin{cases} J\,(U^{(k)})\,\Delta U^{(k)} = -\rho(U^{(k)}) \\ U^{(k+1)} = U^{(k)} + \lambda_k \,\Delta\, U^{(k)} \end{cases}$$

FIG. 21

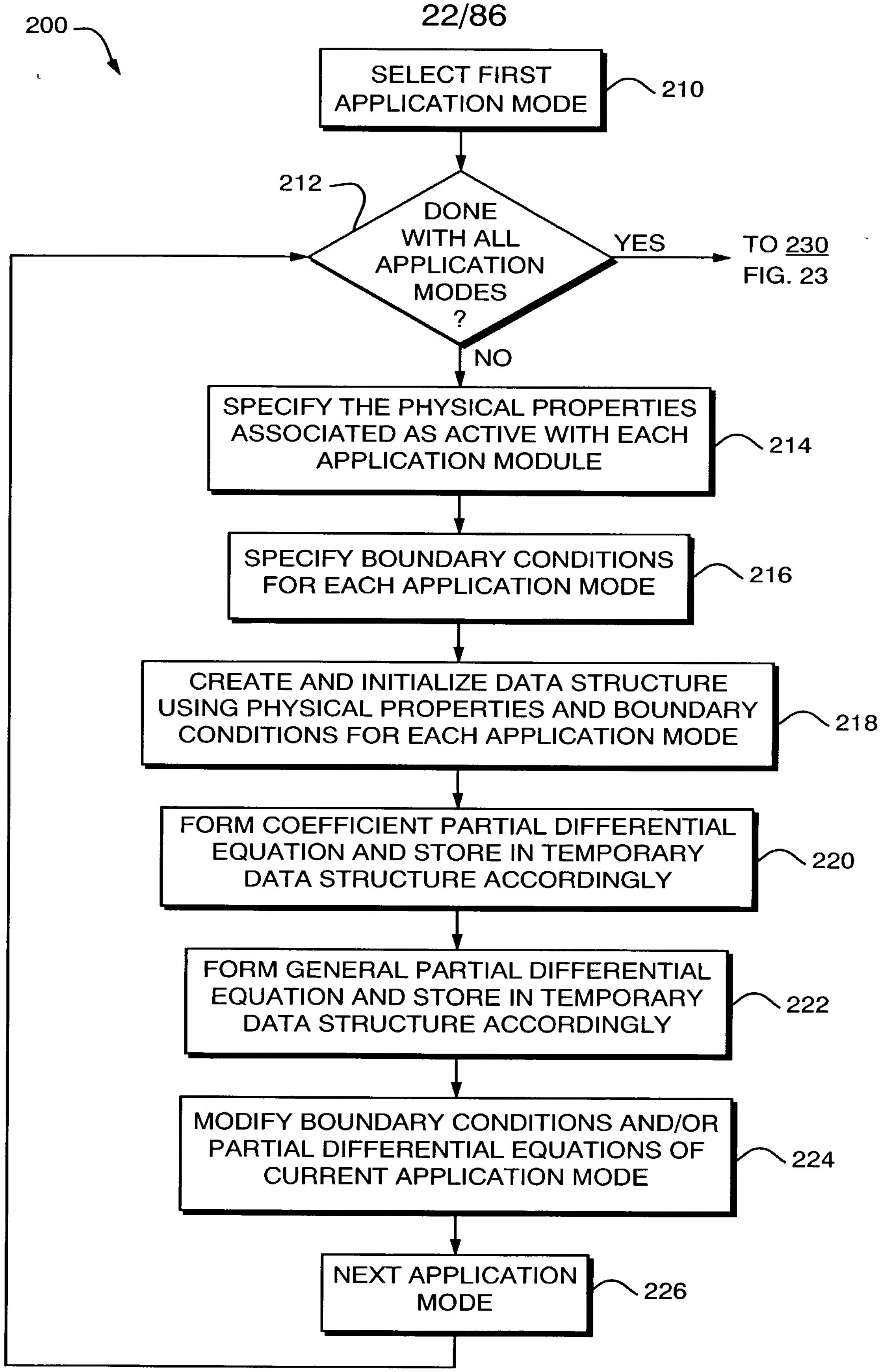

200
SELECT FIRST APPLICATION MODE
210
212
DONE WITH ALL APPLICATION MODES ?
YES
TO 230 FIG. 23
NO
SPECIFY THE PHYSICAL PROPERTIES ASSOCIATED AS ACTIVE WITH EACH APPLICATION MODULE
214
SPECIFY BOUNDARY CONDITIONS FOR EACH APPLICATION MODE
216
CREATE AND INITIALIZE DATA STRUCTURE USING PHYSICAL PROPERTIES AND BOUNDARY CONDITIONS FOR EACH APPLICATION MODE
218
FORM COEFFICIENT PARTIAL DIFFERENTIAL EQUATION AND STORE IN TEMPORARY DATA STRUCTURE ACCORDINGLY
220
FORM GENERAL PARTIAL DIFFERENTIAL EQUATION AND STORE IN TEMPORARY DATA STRUCTURE ACCORDINGLY
222
MODIFY BOUNDARY CONDITIONS AND/OR PARTIAL DIFFERENTIAL EQUATIONS OF CURRENT APPLICATION MODE
224
NEXT APPLICATION MODE
226

FIG. 22

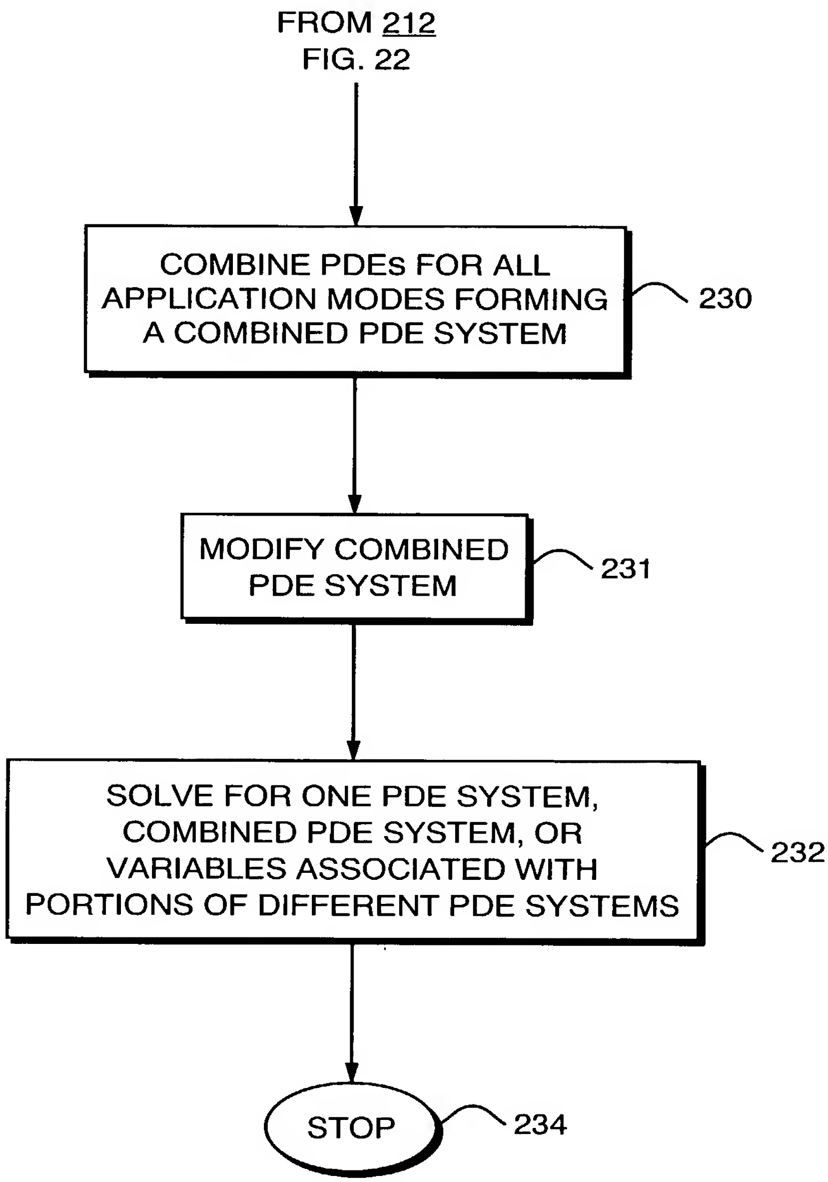

FROM 212
FIG. 22
COMBINE PDEs FOR ALL APPLICATION MODES FORMING A COMBINED PDE SYSTEM
230
MODIFY COMBINED PDE SYSTEM
231
SOLVE FOR ONE PDE SYSTEM, COMBINED PDE SYSTEM, OR VARIABLES ASSOCIATED WITH PORTIONS OF DIFFERENT PDE SYSTEMS
232
STOP
234

FIG. 23

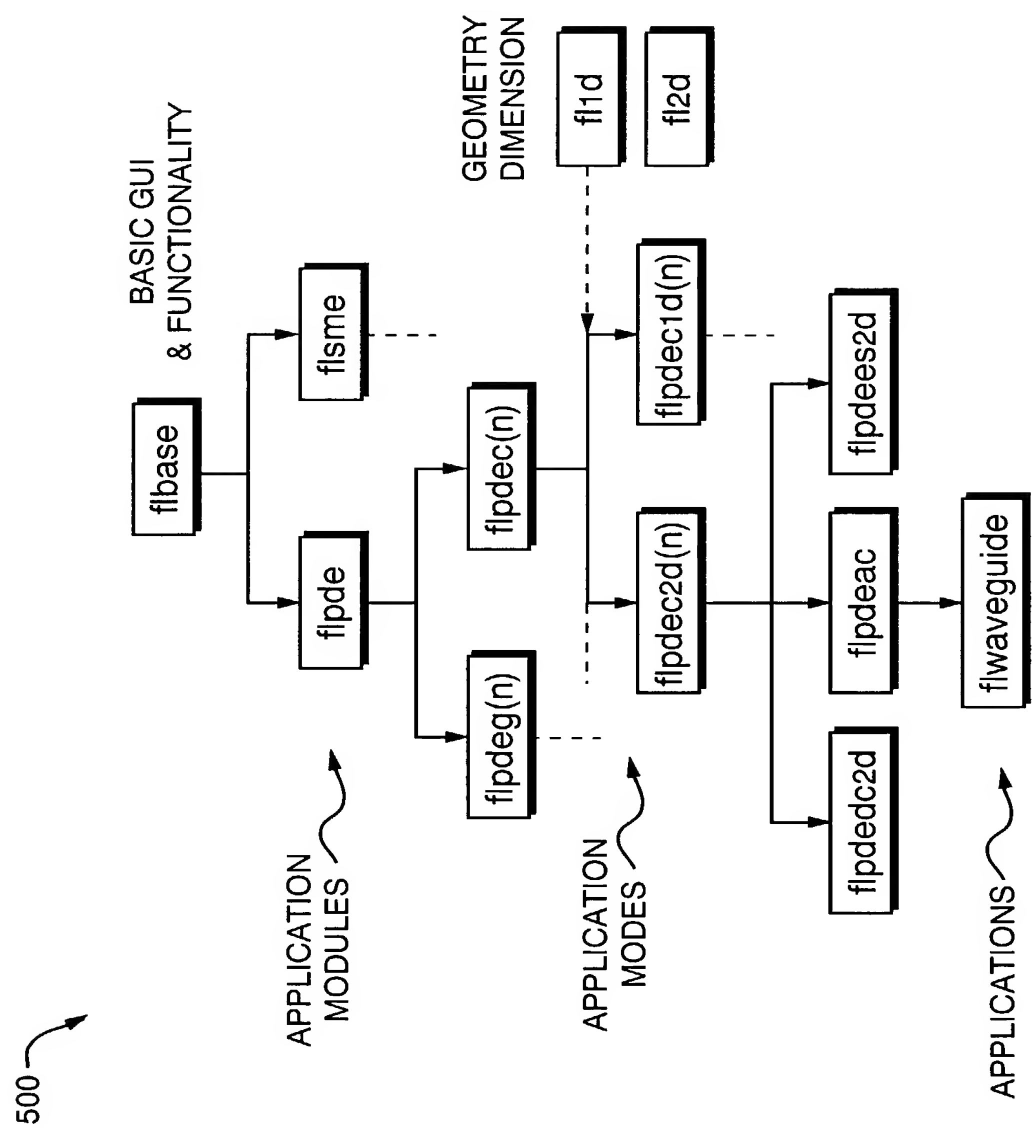

500
BASIC GUI & FUNCTIONALITY
GEOMETRY DIMENSION
flbase
flpde
flsme
flpdeg(n)
flpdec(n)
fl1d
fl2d
flpdec1d(n)
flpdec2d(n)
flpdedc2d
flpdeac
flpdees2d
flwaveguide
APPLICATION MODULES
APPLICATION MODES
APPLICATIONS

FIG. 24

1-D PHYSICS APPLICATION MODES

APPLICATION MODE	CLASS NAME	PARENT CLASS
DIFFUSION	flpdedf1d	flpdedf
HEAT TRANSFER	flpdeht1d	flpdeht

502

1-D PDE APPLICATION MODES

APPLICATION MODE	CLASS NAME	PARENT CLASS
COEFFICIENT PDE MODEL, n VARIABLES	flpdecf1d*(n)*	flpdecf*(n)*
GENERAL PDE MODEL, n VARIABLES	flpdegt1d*(n)*	flpdegt*(n)*

504

FIG. 25

2-D PHYSICS APPLICATION MODES

APPLICATION MODE	CLASS NAME	PARENT CLASS
AC POWER ELECTROMAGNETICS	flpdeac	flpdec2d
CONDUCTIVE MEDIA DC	flpdedc2d	flpdedc
DIFFUSION	flpdedf2d	flpdedf
ELECTROSTATICS	flpdees2d	flpdees
MAGNETOSTATICS	flpdems2d	flpdems
HEAT TRANSFER	flpdeht2d	flpdeht
INCOMPRESSIBLE NAVIER-STOKES	flpdens2d	flpdens
STRUCTURAL MECHANICS, PLANE STRESS	flpdeps	flpdec2d
STRUCTURAL MECHANICS, PLANE STRAIN	flpdepn	flpdec2d

506

PDE APPLICATION MODES

APPLICATION MODE	CLASS NAME	PARENT CLASS
COEFFICIENT PDE MODEL, n VARIABLES	flpdec2d*(n)*	flpdec*(n)*
GENERAL PDE MODEL, n VARIABLES	flpdeg2d*(n)*	flpdeg*(n)*

508

FIG. 26

APPLICATION OBJECT PROPERTIES

Property name	Description	Data type
dim	Names of the dependent variables	Cell array of strings
form	PDE form	String (coefficient/general)
name	Application name	String
parent	Parent class names	String, cell array of strings, or the empty matrix
sdim	Names of the independent variables (space dimensions)	Cell array of strings
submode	Name of current submode	String (std/wave)
tdiff	Time differentiation flag	String (on/off)

510

FIG. 27

512

```
function obj = myapp()
%MYAPP Constructor for a FEMLAB appplication object.

obj.name = 'My first FEMLAB application';
obj.parent = 'flpdeht2d':

%MYAPP is a subclass of FLPDEHT2D;
p1 = flpdeht2d;
obj = class(obj,'myapp',p1);
sat(obj,'dim',default_dim(obj));
```

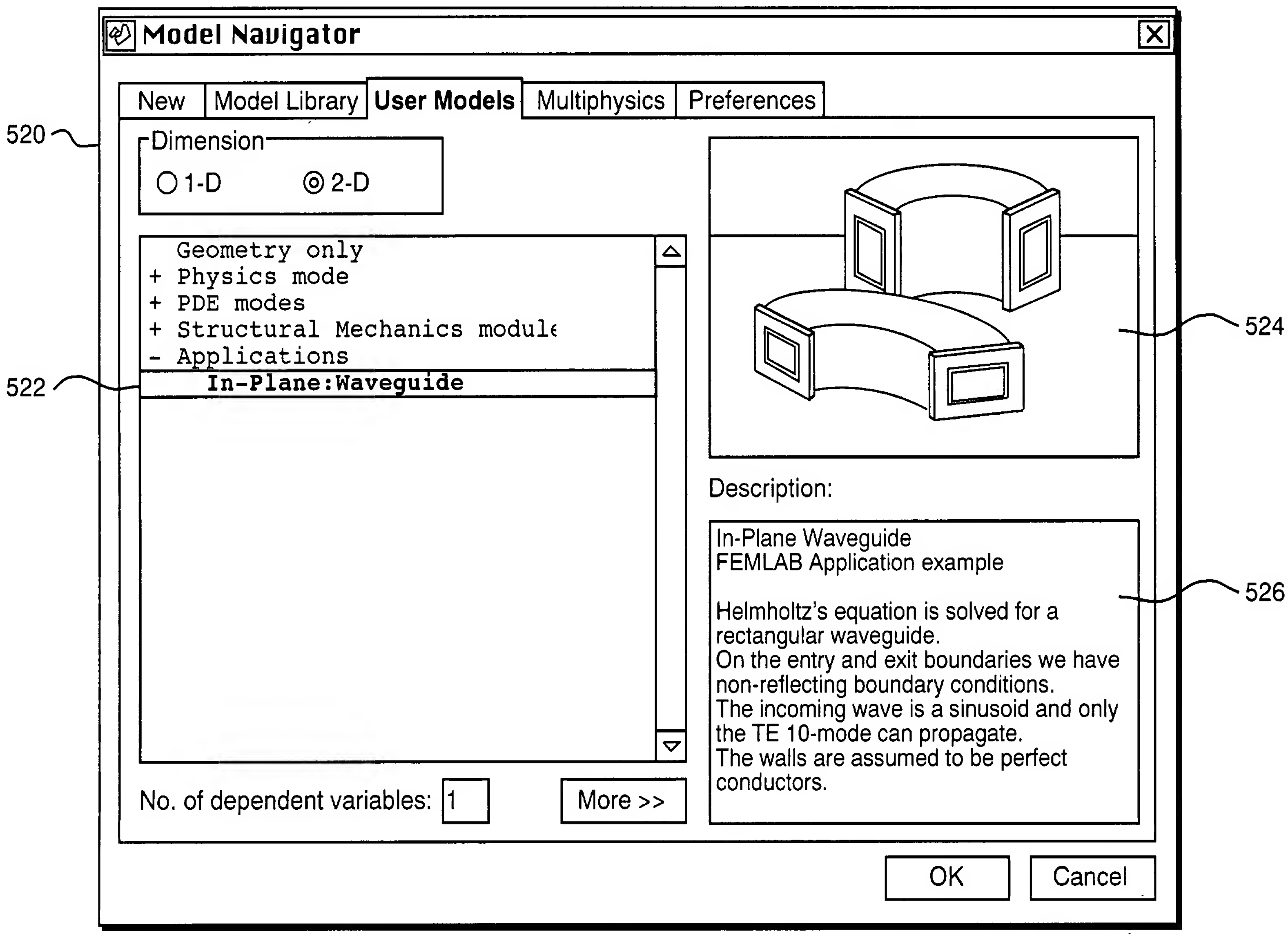
FIG. 28

PHYSICS MODELING METHODS

514

FUNCTION	PURPOSE
appspec	Return application specifications
bnd_compute	Convert application-dependent boundary conditions to generic boundary coefficients.
default_bnd	Default boundary conditions.
default_dim	Default names of dependent variables.
default_equ	Default PDE coefficients/material parameters.
default_init	Default intitial conditions.
default_sdim	Default space dimension variables.
default_var	Default application scalar variables.
dim_compute	Return dependent variables for an application
equ_compute	Convert application-dependent material parameters to generic PDE coefficients.
form_compute	Return PDE form.
init_compute	Convert application-dependent initial conditions to generic initial conditions.
posttable	Define assigned variable names and post-processing information.

FIG. 29



Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Dimension
1-D
2-D
Geometry only
+ Physics mode
+ PDE modes
+ Structural Mechanics module
- Applications
In-Plane:Waveguide
No. of dependent variables: 1
More >>
Description:
In-Plane Waveguide
FEMLAB Application example
Helmholtz's equation is solved for a rectangular waveguide.
On the entry and exit boundaries we have non-reflecting boundary conditions.
The incoming wave is a sinusoid and only the TE 10-mode can propagate.
The walls are assumed to be perfect conductors.
OK
Cancel
520
522
524
526

FIG. 30

FIG. 31

530 $\left\{ \Delta E_z + (2\pi ik)^2 E_z = 0 \right.$

532 $\left\{ k = \frac{1}{\lambda} = \frac{f}{c} \right.$

534 $\left\{ \bar{n}, (\nabla E_z) + 2\pi ik_x E_z = 4\pi ik_x \sin\left(\frac{\pi}{d}(y - y_0)\right) \right.$

536 $\left\{ k^2 = k_x^2 + k_y^2 \right.$

538 $\left\{ k_x = \sqrt{\frac{1}{\lambda^2} - \frac{1}{(2d)^2}} \right.$

540 $\left\{ n \cdot (\nabla E_z) + 2\pi ik_x E_z = 0 \right.$

542 $\left\{ E_z = 0 \right.$

544 $\left\{ f_c = \frac{c}{2d} \right.$

550

```
function obj = flwaveguide(varargin)
%FLWAVEGUIDE Constructor for a Waveguide application object.

obj.name = 'In-Plane Waveguide';
obj.parent = 'flpdeac';

%FLWAVEGUIDE is a subclass of FLPDEAC:
p1 = flpdeac;
obj = class(obj,'flwaveguide',p1);
set(obj,'dim',default_dim(obj));
```

FIG. 32

552

fem user field

field	description
geomparam	1-by-2 structure of geometry parameters.
entrybnd	Index to the entry boundary.
exitbnd	Index to the exit boundary.
freqs	Frequency vector

FIG. 33

554

fem user field

field	description
startpt	Index of the lower left corner point of the waveguide.
type	Type of waveguide. (*'straight or 'elbow)*

FIG. 34

geoparam fields

field	description	defaults for elbow	default for straight
entrylength	Length of the entrance part of the waveguide.	0.1	0.1
exitlength	Length of the exit part of the waveguide.	0.1	not used
radius	Outer radius of the waveguide bend.	0.05	not used
width	Width of the waveguide.	0.025	0.025
cavityflag	Turn resonance cavity *on* or *off*.	0	0
cavitywidth	Width of the resonance cavity.	0.025	0.025
postwidth	Width of the protruding posts.	0.005	0.005
postdepth	Depth of the protruding posts.	0.005	0.005

FIG. 35

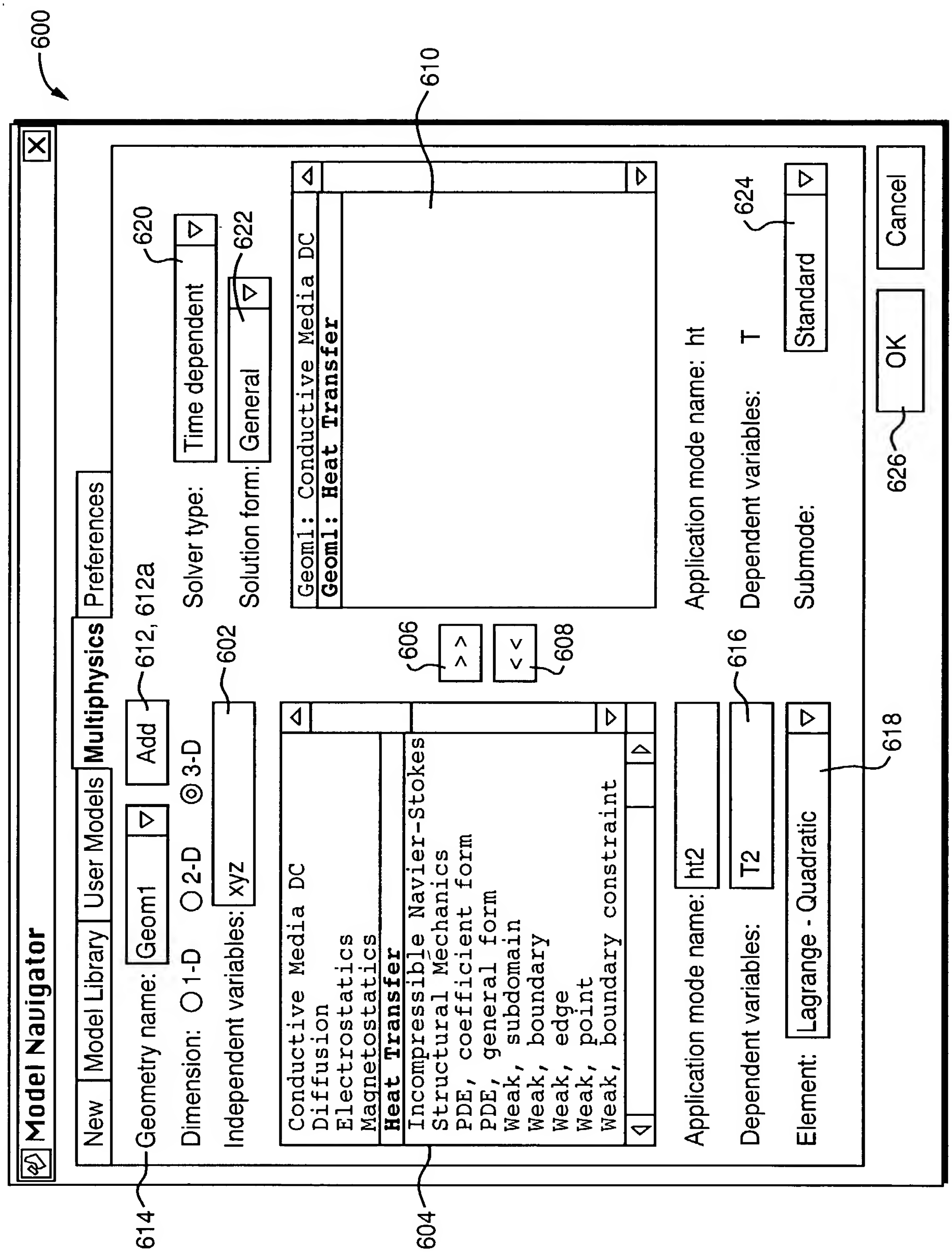

600
Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Geometry name:
Geom1
Add
Dimension:
1-D
2-D
3-D
Independent variables:
xyz
Solver type:
Time dependent
Solution form:
General
Conductive Media DC
Diffusion
Electrostatics
Magnetostatics
Heat Transfer
Incompressible Navier-Stokes
Structural Mechanics
PDE, coefficient form
PDE, general form
Weak, subdomain
Weak, boundary
Weak, edge
Weak, point
Weak, boundary constraint
>>
<<
Geom1: Conductive Media DC
Geom1: Heat Transfer
Application mode name:
ht2
Dependent variables:
T2
Element:
Lagrange - Quadratic
Application mode name: ht
Dependent variables: T
Submode:
Standard
OK
Cancel
614
604
612, 612a
602
606
608
610
616
618
620
622
624
626

FIG. 36

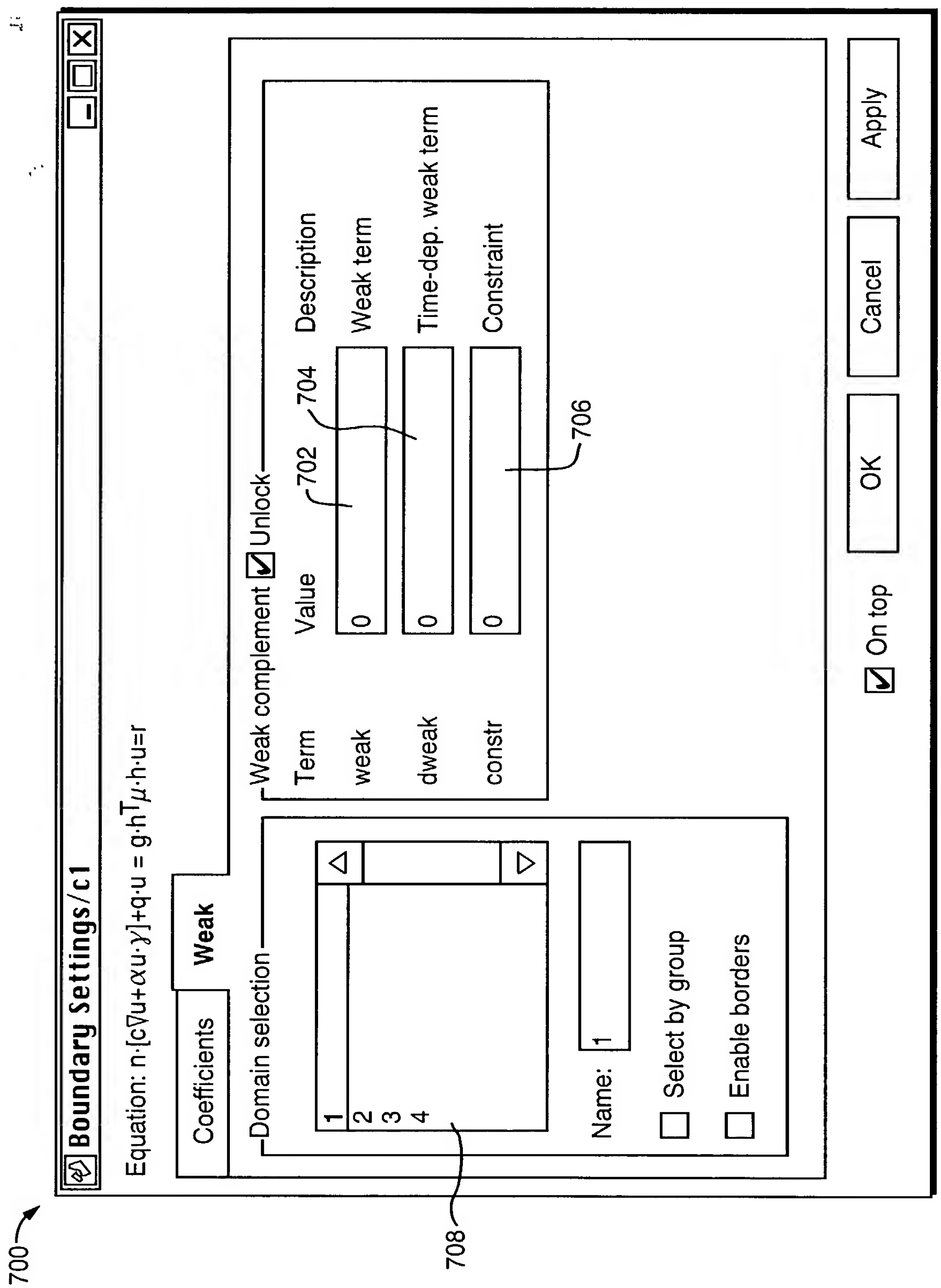

700
Boundary Settings/c1
Equation: $n\cdot[c\nabla u+\alpha u\cdot\gamma]+q\cdot u = g\cdot h^T\mu\cdot h\cdot u=r$
Coefficients
Weak
Domain selection
1
2
3
4
Name: 1
Select by group
Enable borders
708
Weak complement
Unlock
Term
Value
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
702
704
706
On top
OK
Cancel
Apply

FIG. 37

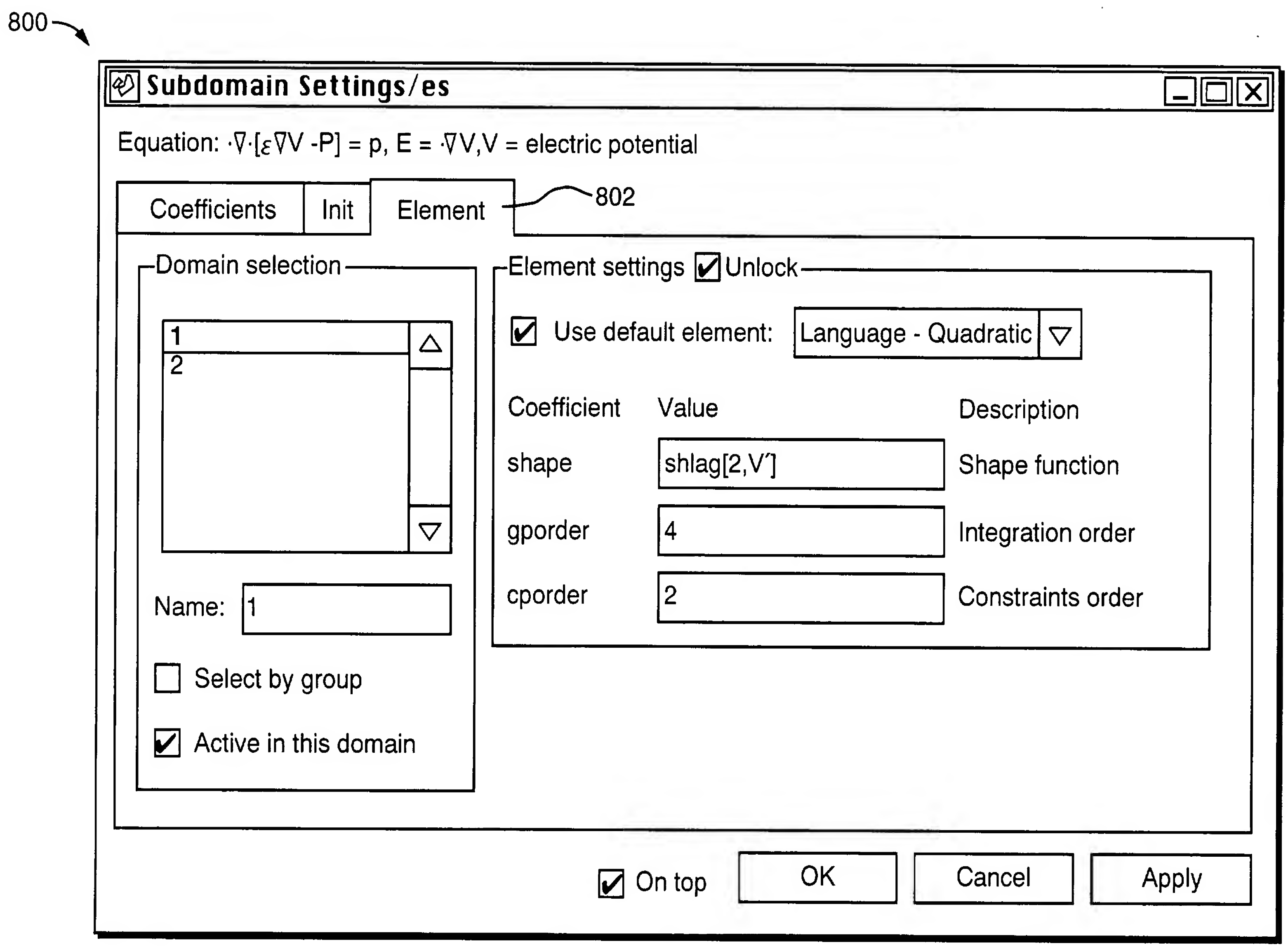

800
Subdomain Settings/es
Equation: ·∇·[ε∇V -P] = p, E = ·∇V,V = electric potential
Coefficients
Init
Element
802
Domain selection
1
2
Name: 1
Select by group
Active in this domain
Element settings
Unlock
Use default element:
Language - Quadratic
Coefficient
Value
Description
shape
shlag[2,V']
Shape function
gporder
4
Integration order
cporder
2
Constraints order
On top
OK
Cancel
Apply

FIG. 38

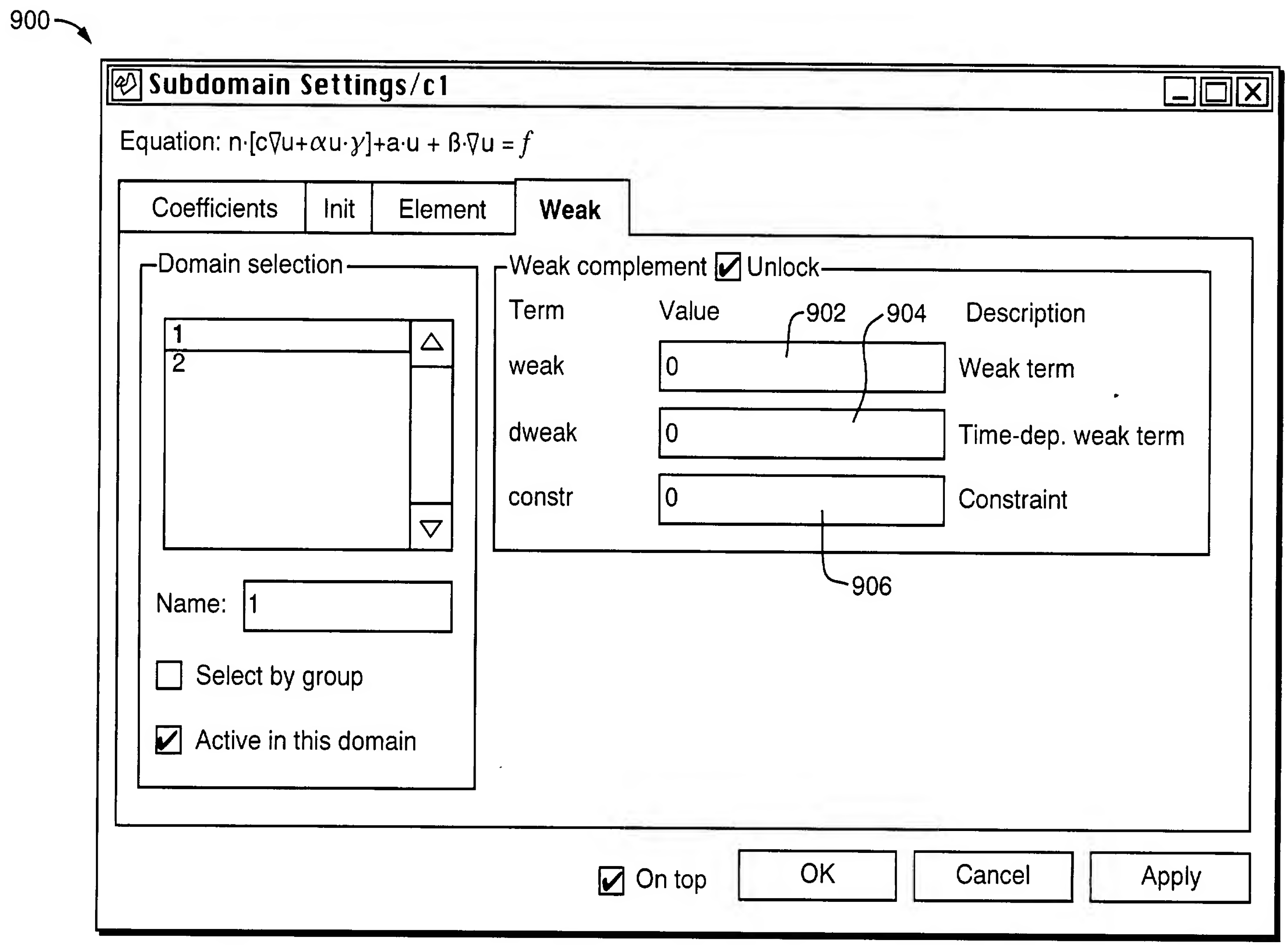
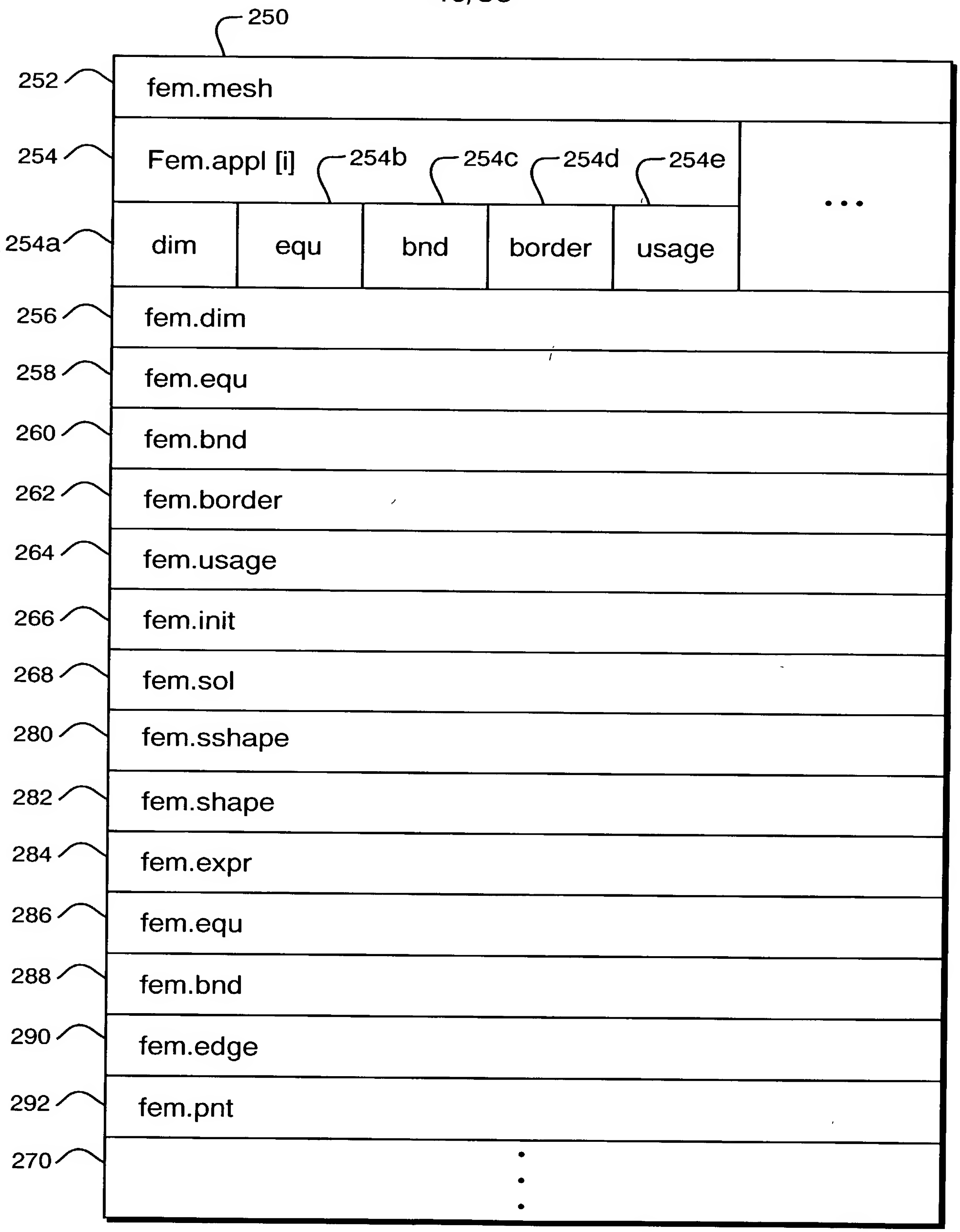

900
Subdomain Settings/c1
Equation: n·[c∇u+αu·γ]+a·u + β·∇u = f
Coefficients
Init
Element
Weak
Domain selection
1
2
Name:
1
Select by group
Active in this domain
Weak complement
Unlock
Term
Value
902
904
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
906
On top
OK
Cancel
Apply

FIG. 39



250
252
fem.mesh
254
Fem.appl [i]
254b
254c
254d
254e
254a
dim
equ
bnd
border
usage
...
256
fem.dim
258
fem.equ
260
fem.bnd
262
fem.border
264
fem.usage
266
fem.init
268
fem.sol
280
fem.sshape
282
fem.shape
284
fem.expr
286
fem.equ
288
fem.bnd
290
fem.edge
292
fem.pnt
270

FIG. 40

$$
1100 \begin{cases}
1102 \begin{cases}
0 = \int\limits_{\Omega} W^{(2)} \, d A \ \int\limits_{B} W^{(1)} ds + \sum\limits_{P} W^{(0)} + \\
+ \int\limits_{\Omega} v_l \frac{\partial R_m^{(2)}}{\partial U_l} \mu_m^{(2)} \, dA + \int\limits_{B} v_l \frac{\partial Rm^{(1)}}{\partial u_l} \mu_m^{(1)} ds + \sum\limits_{P} v_l \frac{\partial Rm^{(0)}}{\partial u_l} \mu_m^{(0)}
\end{cases} \\
1104 \begin{cases}
0 = R^{(2)} & \text{on } \Omega \\
0 = R^{(1)} & \text{on } B \\
0 = R^{(0)} & \text{on } P
\end{cases}
\end{cases}
$$

FIG. 41

$$
1200 \begin{cases}
W_l^{(n)} = W_l^{(n)} + \Gamma_{lj} \dfrac{\partial v_l}{\partial x_j} + F_l v_l \\[2ex]
W_l^{(nt)} = W_l^{(nt)} + d_{alk} \dfrac{\partial u_k}{\partial t} v_l \\[2ex]
W_l^{(n-l)} = W_l^{(n-l)} + G_{lvl} \\[2ex]
R_m^{(n)} = R_m
\end{cases}
$$

FIG. 42

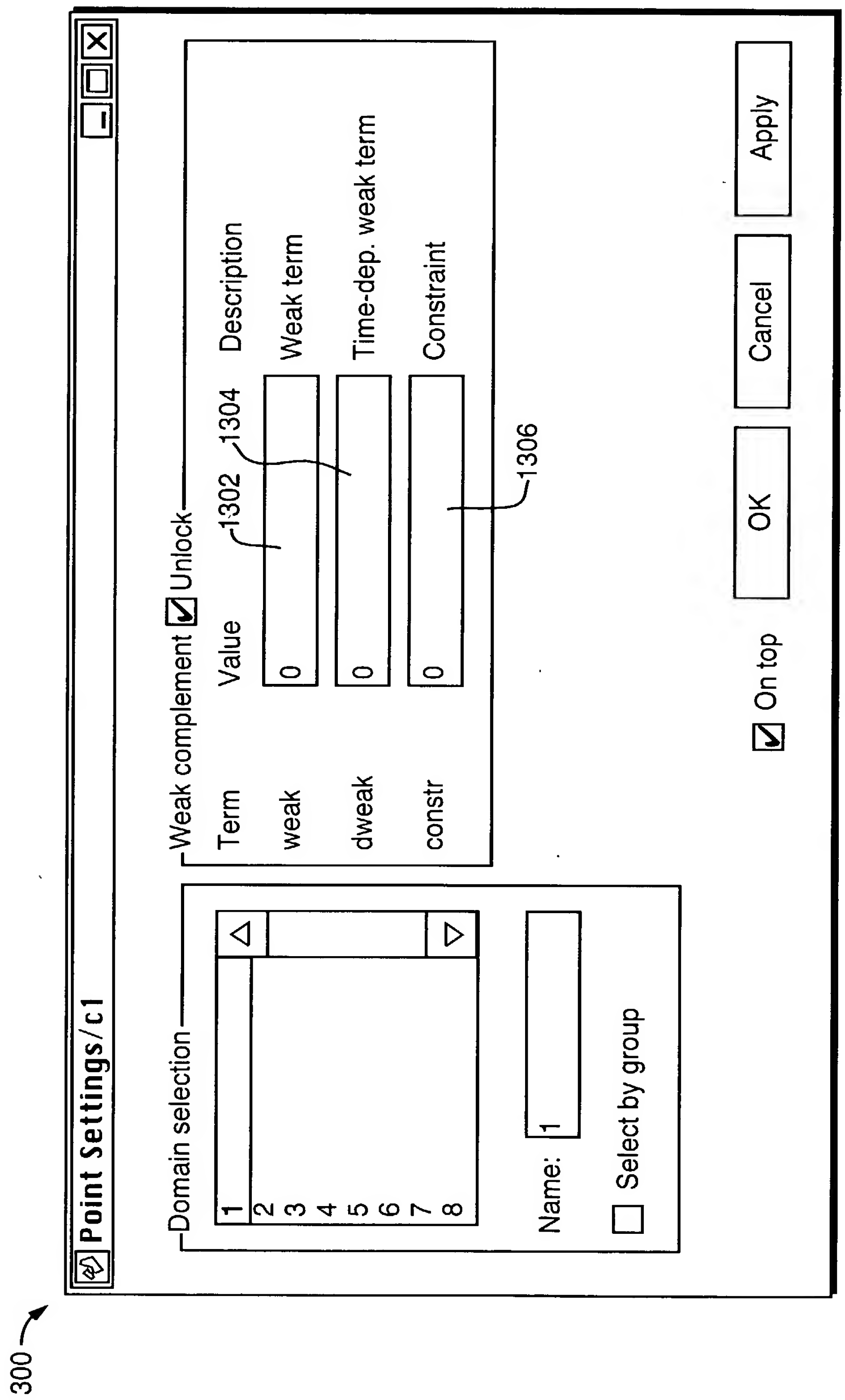

1300
Point Settings/c1
Domain selection
1
2
3
4
5
6
7
8
Name:
1
Select by group
Weak complement
Unlock
Term
Value
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
1302
1304
1306
On top
OK
Cancel
Apply

FIG. 43

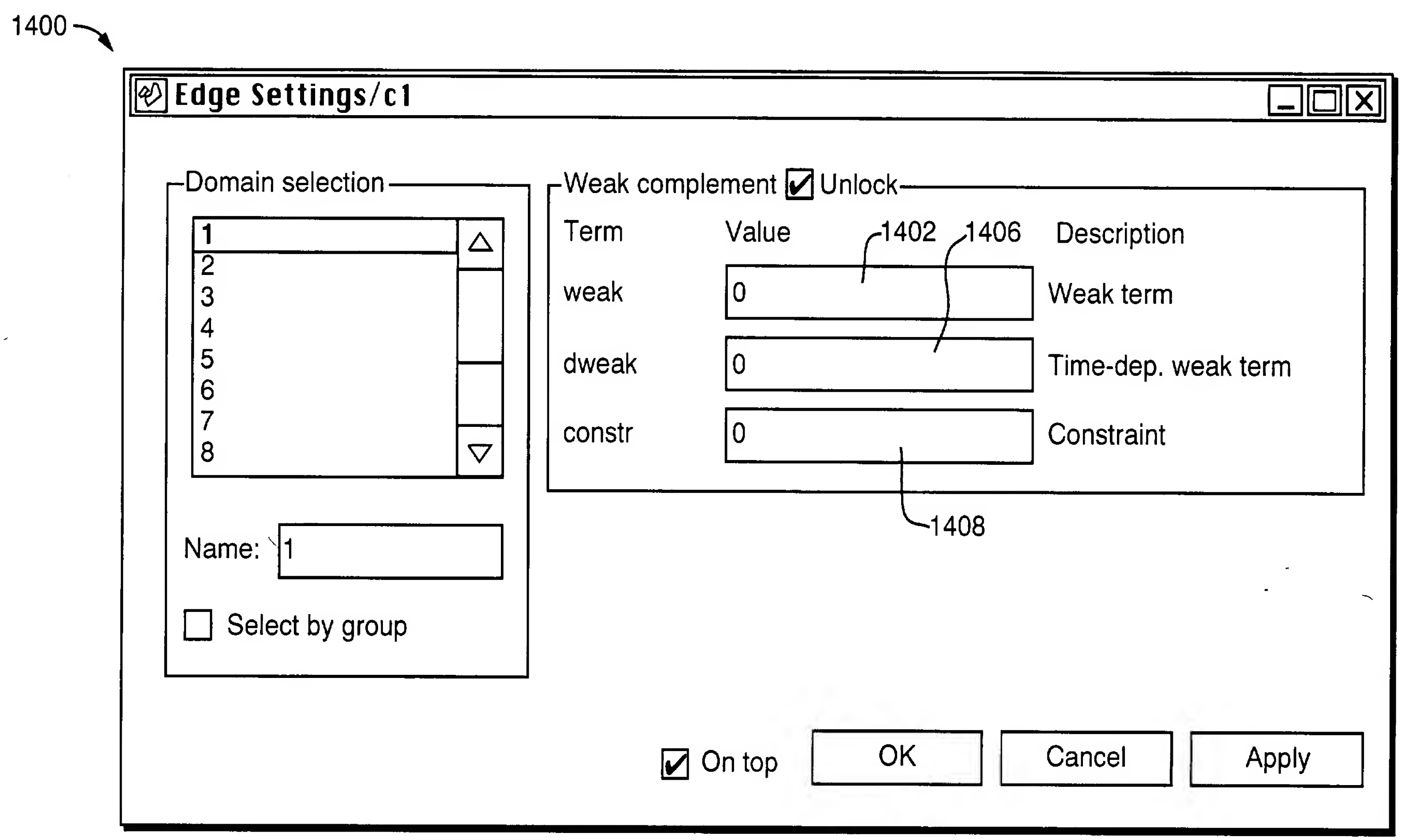

1400
Edge Settings/c1
Domain selection
1
2
3
4
5
6
7
8
Name:
1
Select by group
Weak complement
Unlock
Term
Value
1402
1406
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
1408
On top
OK
Cancel
Apply

FIG. 44

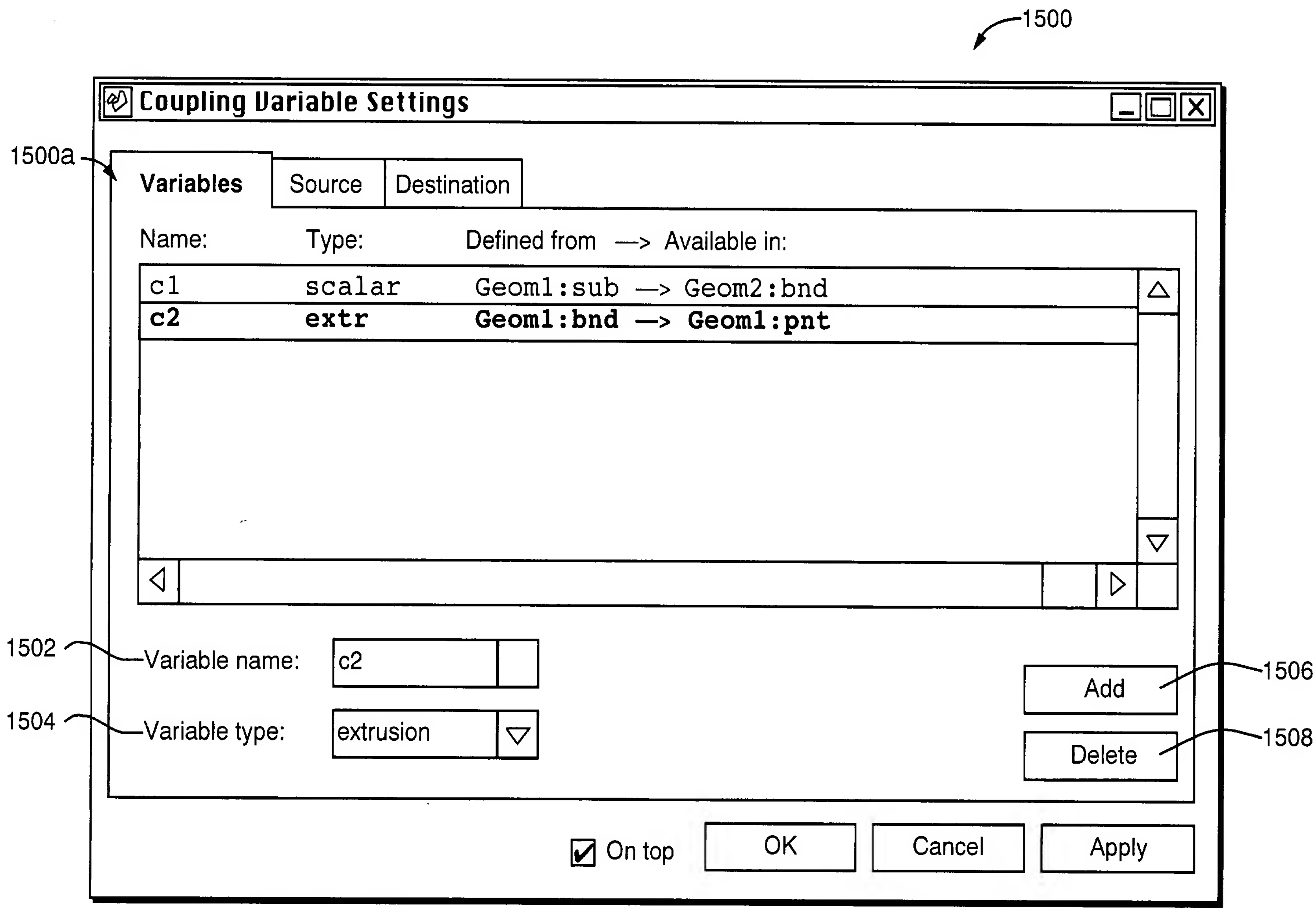

1500
Coupling Variable Settings
1500a
Variables
Source
Destination
Name:
Type:
Defined from —> Available in:
c1 scalar Geom1:sub —> Geom2:bnd
c2 extr Geom1:bnd —> Geom1:pnt
1502
Variable name:
c2
1504
Variable type:
extrusion
Add
1506
Delete
1508
On top
OK
Cancel
Apply

FIG. 45A

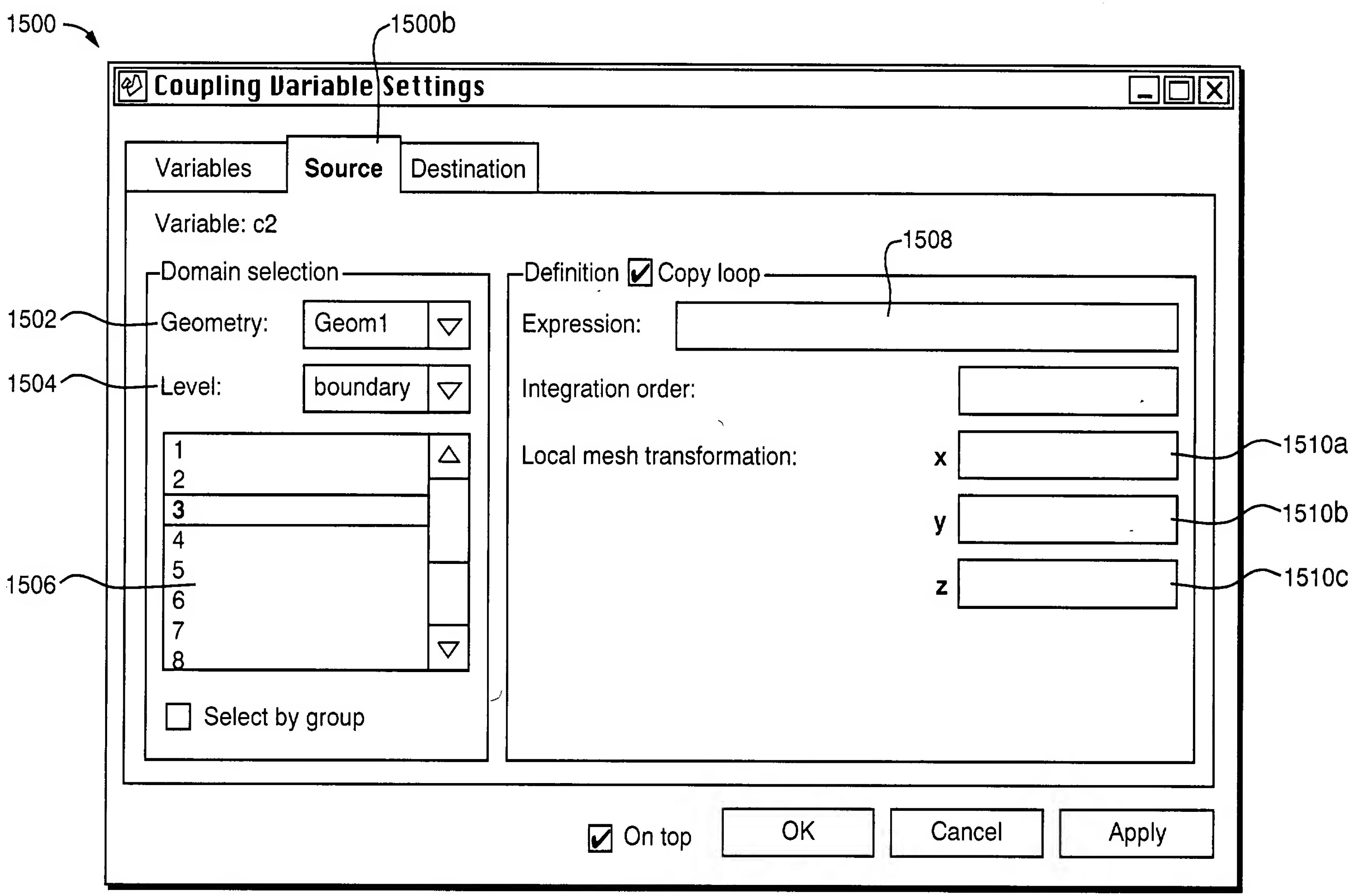

1500
1500b
Coupling Variable Settings
Variables
Source
Destination
Variable: c2
Domain selection
1502
Geometry:
Geom1
1504
Level:
boundary
1
2
3
4
5
1506
6
7
8
Select by group
Definition
Copy loop
1508
Expression:
Integration order:
Local mesh transformation:
x
1510a
y
1510b
z
1510c
On top
OK
Cancel
Apply

FIG. 45B

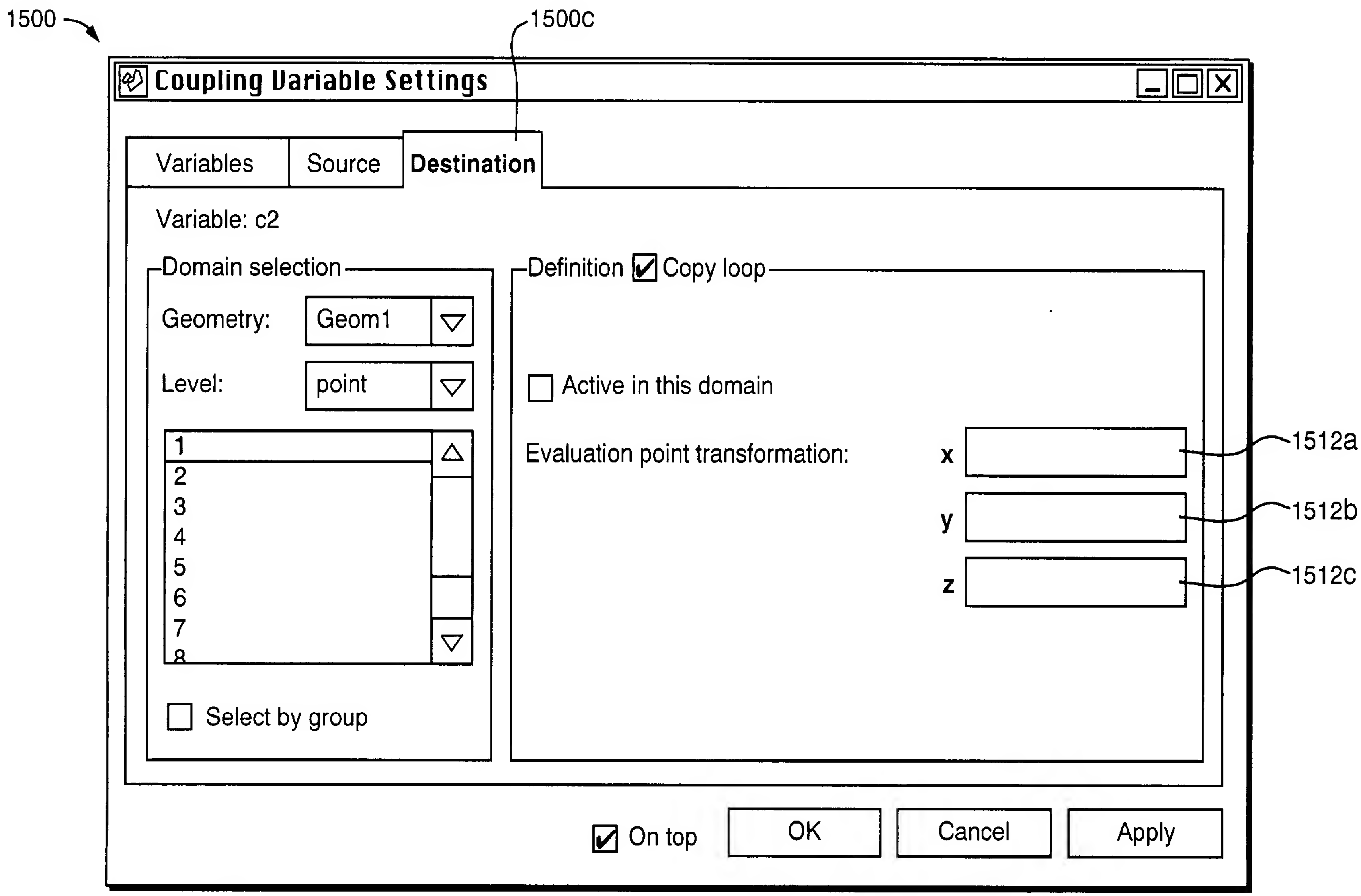

1500
1500C
Coupling Variable Settings
Variables
Source
Destination
Variable: c2
Domain selection
Geometry:
Geom1
Level:
point
1
2
3
4
5
6
7
8
Select by group
Definition
Copy loop
Active in this domain
Evaluation point transformation:
x
y
z
1512a
1512b
1512c
On top
OK
Cancel
Apply

FIG. 45C

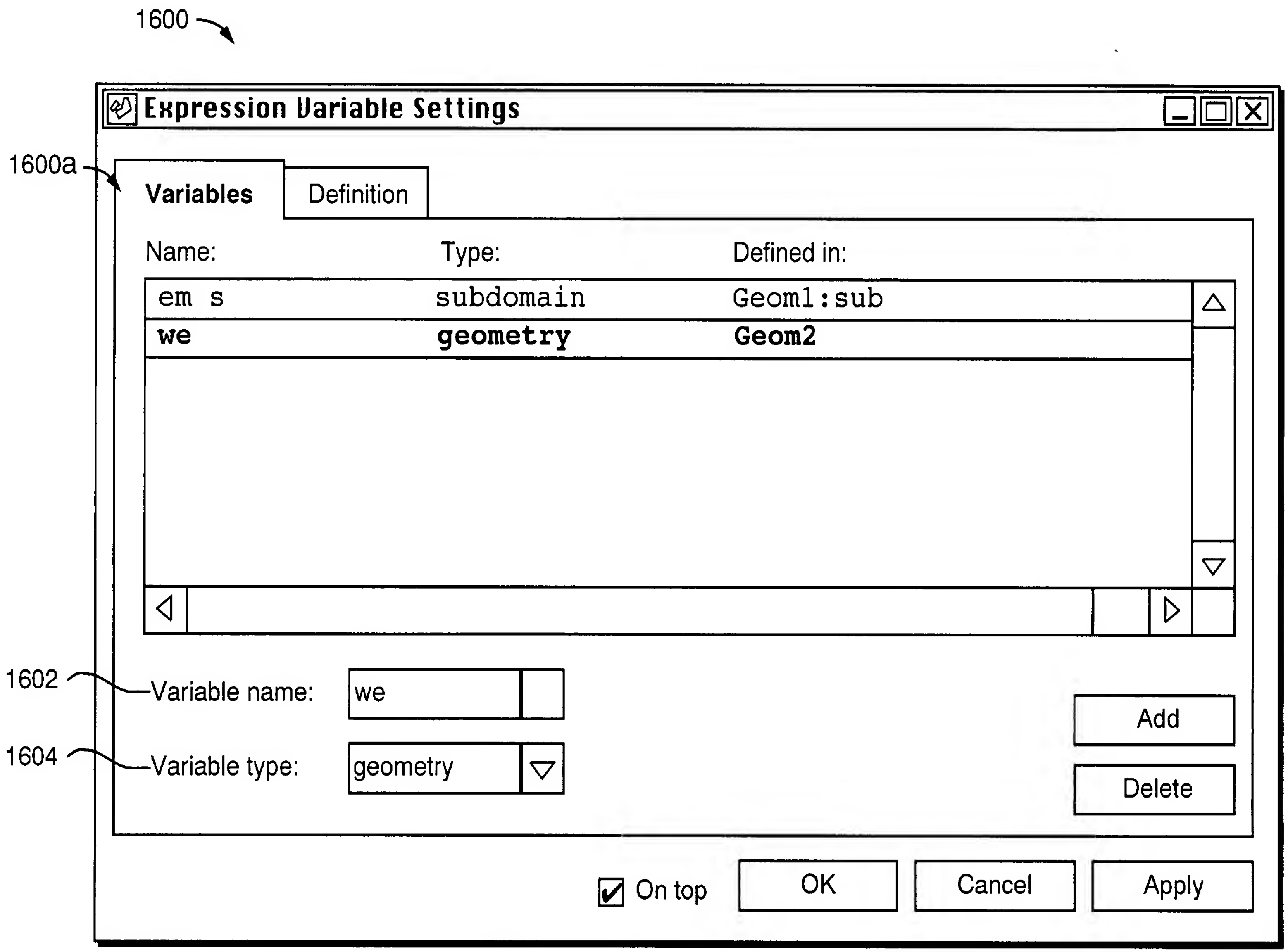

1600
1600a
Expression Variable Settings
Variables
Definition
Name:
Type:
Defined in:
em s
subdomain
Geom1:sub
we
geometry
Geom2
1602
Variable name:
we
1604
Variable type:
geometry
Add
Delete
On top
OK
Cancel
Apply

FIG. 46

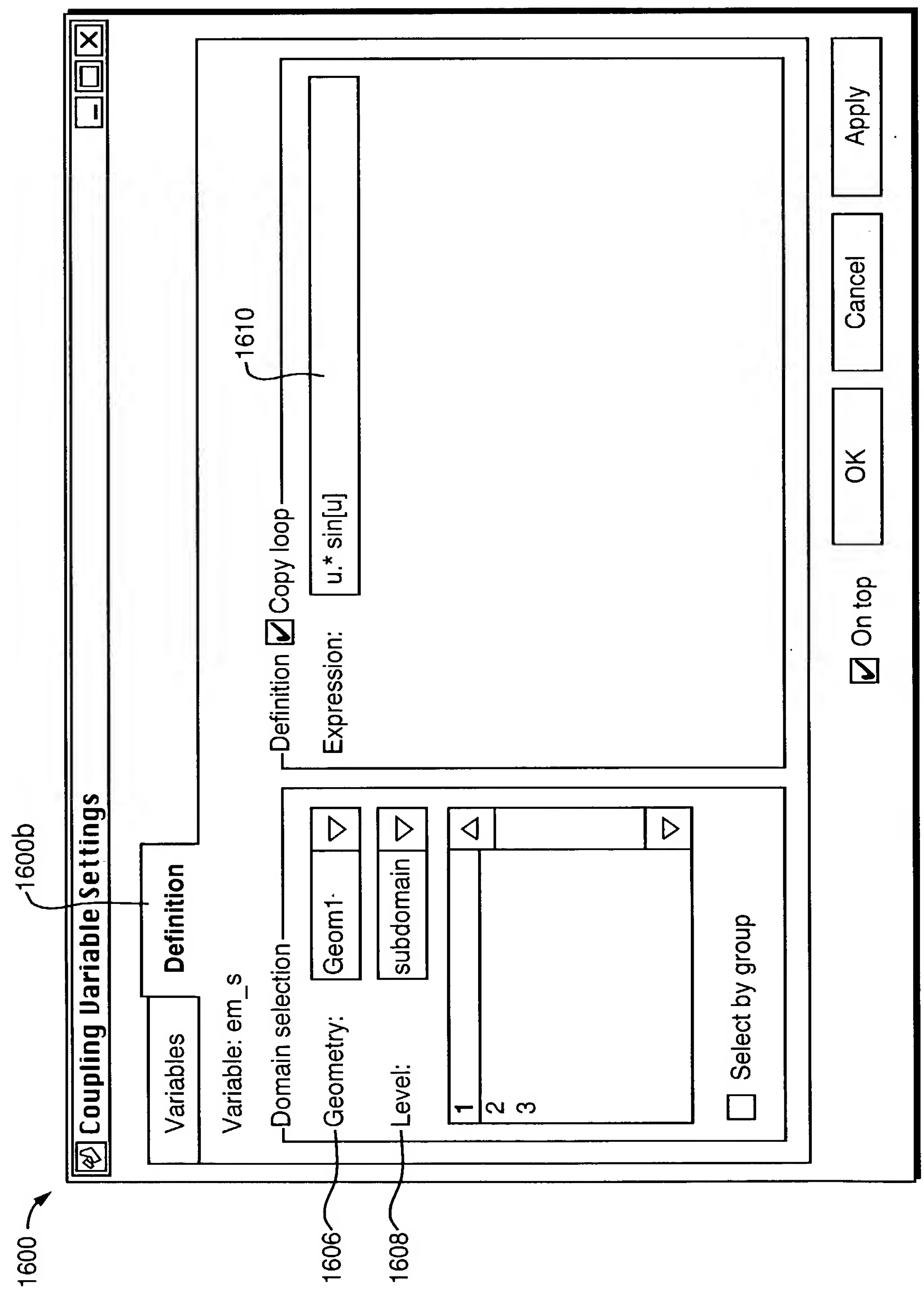

1600
1600b
Coupling Variable Settings
Variables
Definition
Variable: em_s
Domain selection
Geometry:
Geom1
Level:
subdomain
1
2
3
Select by group
1606
1608
Definition
Copy loop
Expression:
u.* sin[u]
1610
On top
OK
Cancel
Apply

FIG. 47

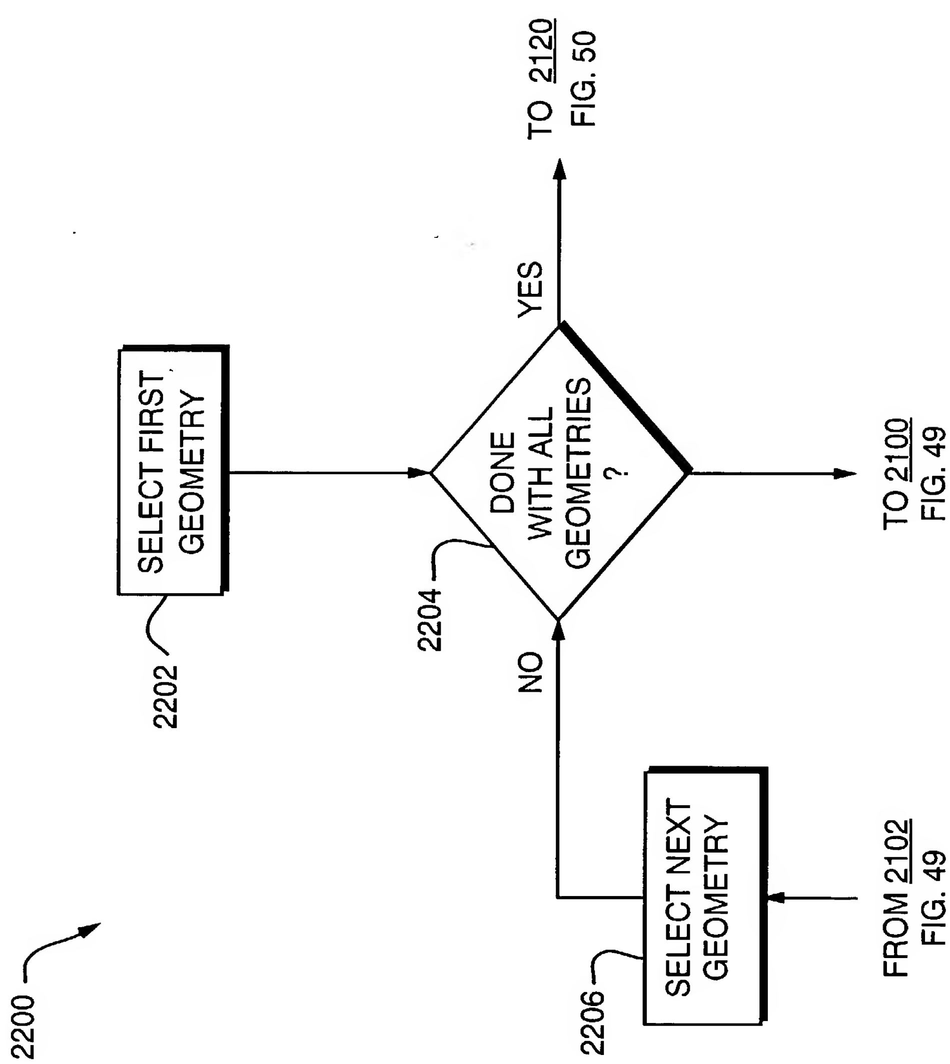

2200
SELECT FIRST GEOMETRY
2202
DONE WITH ALL GEOMETRIES ?
2204
YES
TO 2120 FIG. 50
NO
TO 2100 FIG. 49
SELECT NEXT GEOMETRY
2206
FROM 2102 FIG. 49

FIG. 48

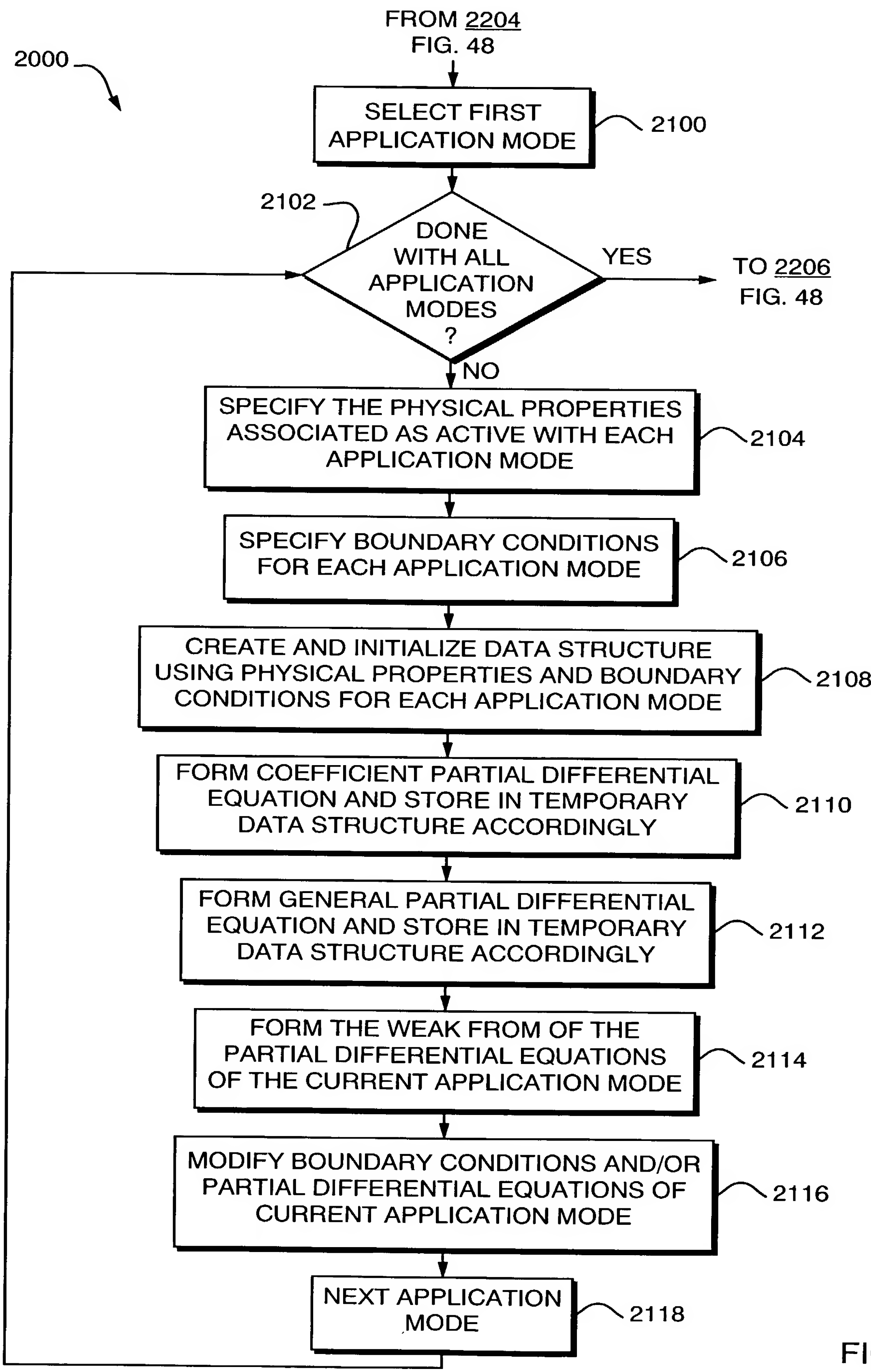

2000
FROM 2204
FIG. 48
SELECT FIRST APPLICATION MODE
2100
2102
DONE WITH ALL APPLICATION MODES ?
YES
TO 2206
FIG. 48
NO
SPECIFY THE PHYSICAL PROPERTIES ASSOCIATED AS ACTIVE WITH EACH APPLICATION MODE
2104
SPECIFY BOUNDARY CONDITIONS FOR EACH APPLICATION MODE
2106
CREATE AND INITIALIZE DATA STRUCTURE USING PHYSICAL PROPERTIES AND BOUNDARY CONDITIONS FOR EACH APPLICATION MODE
2108
FORM COEFFICIENT PARTIAL DIFFERENTIAL EQUATION AND STORE IN TEMPORARY DATA STRUCTURE ACCORDINGLY
2110
FORM GENERAL PARTIAL DIFFERENTIAL EQUATION AND STORE IN TEMPORARY DATA STRUCTURE ACCORDINGLY
2112
FORM THE WEAK FROM OF THE PARTIAL DIFFERENTIAL EQUATIONS OF THE CURRENT APPLICATION MODE
2114
MODIFY BOUNDARY CONDITIONS AND/OR PARTIAL DIFFERENTIAL EQUATIONS OF CURRENT APPLICATION MODE
2116
NEXT APPLICATION MODE
2118

FIG. 49

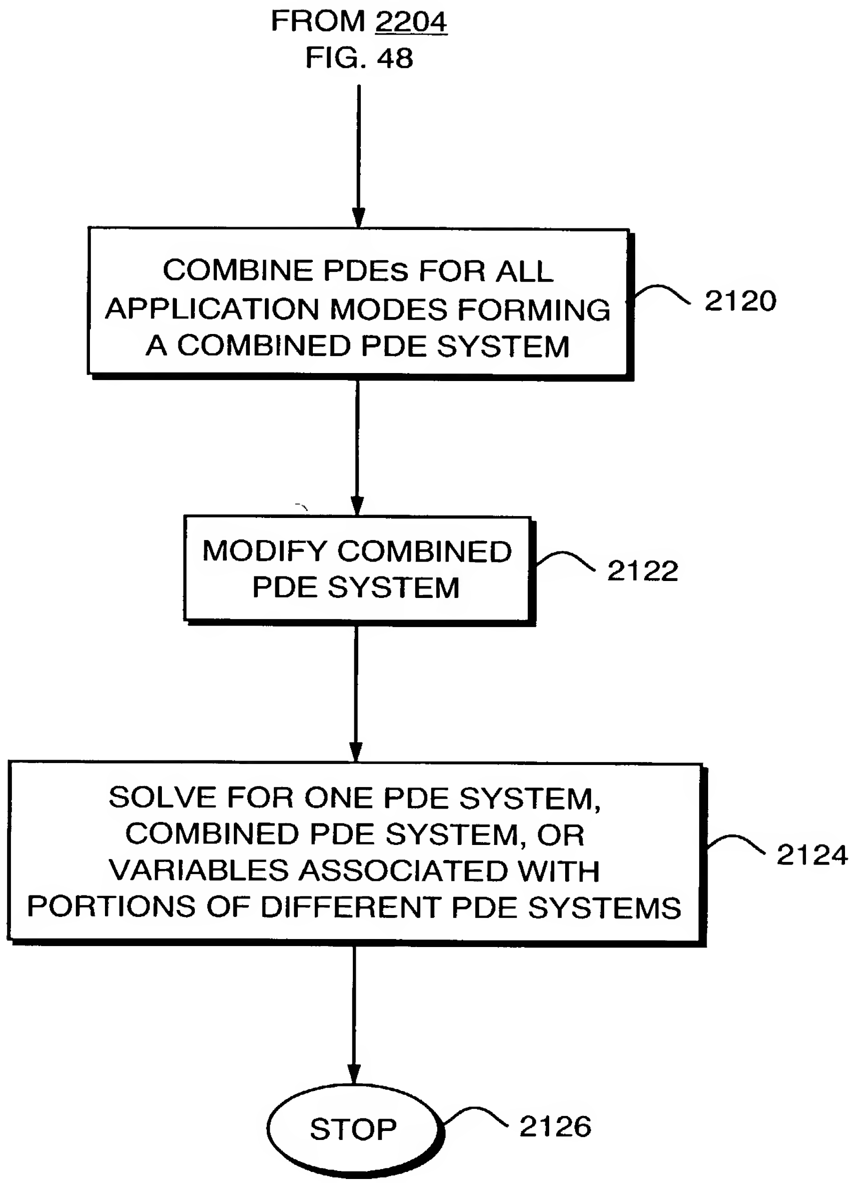

FROM 2204
FIG. 48
COMBINE PDEs FOR ALL APPLICATION MODES FORMING A COMBINED PDE SYSTEM
2120
MODIFY COMBINED PDE SYSTEM
2122
SOLVE FOR ONE PDE SYSTEM, COMBINED PDE SYSTEM, OR VARIABLES ASSOCIATED WITH PORTIONS OF DIFFERENT PDE SYSTEMS
2124
STOP
2126

FIG. 50

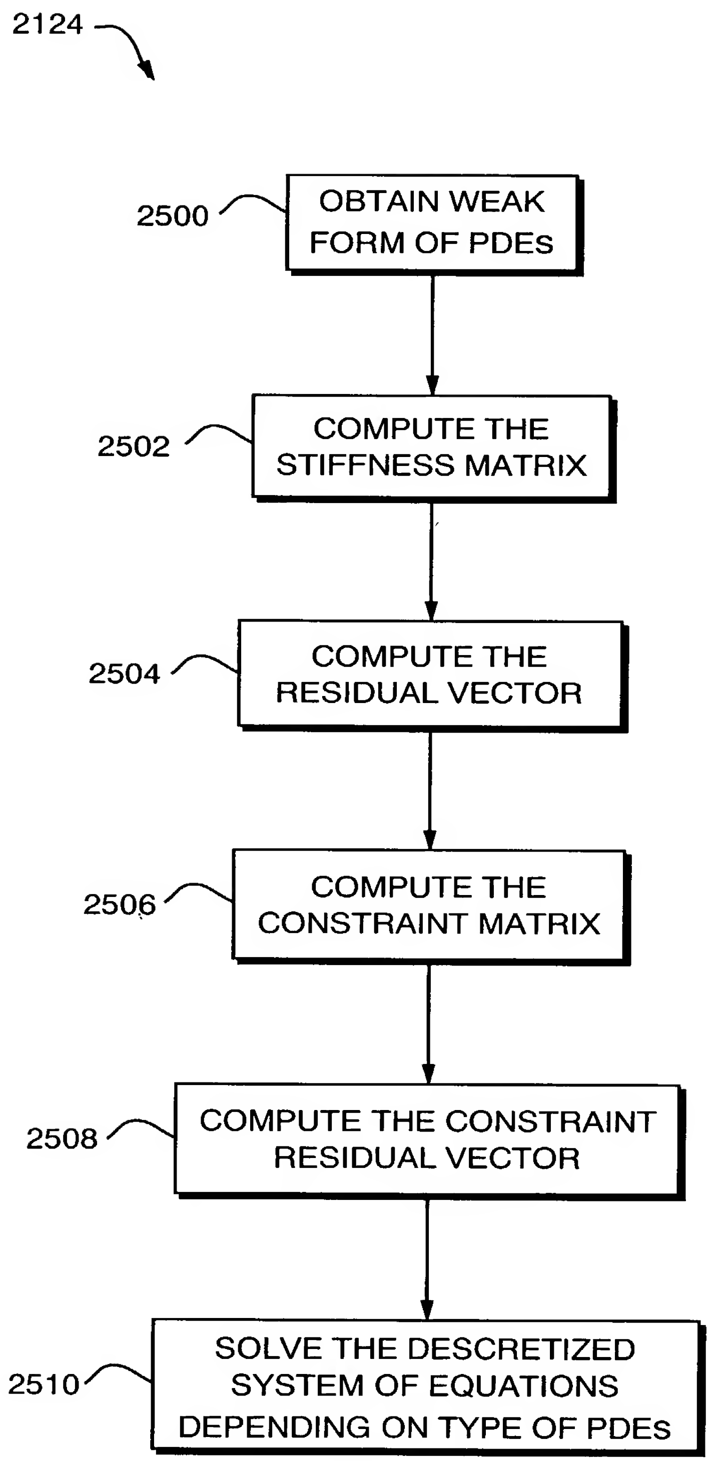

2124
2500
OBTAIN WEAK FORM OF PDEs
2502
COMPUTE THE STIFFNESS MATRIX
2504
COMPUTE THE RESIDUAL VECTOR
2506
COMPUTE THE CONSTRAINT MATRIX
2508
COMPUTE THE CONSTRAINT RESIDUAL VECTOR
2510
SOLVE THE DESCRETIZED SYSTEM OF EQUATIONS DEPENDING ON TYPE OF PDEs

FIG. 51

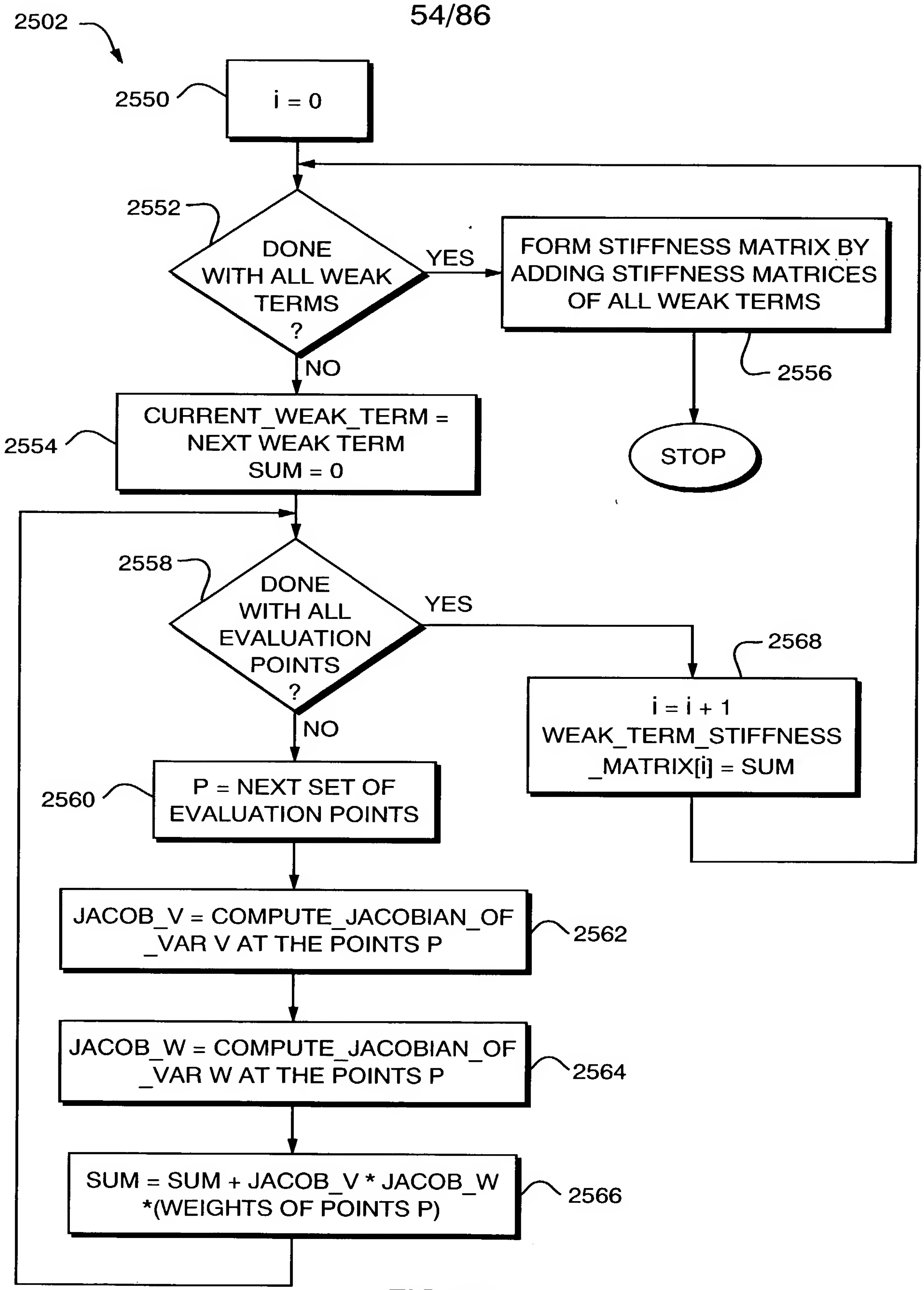

2502
2550
i = 0
2552
DONE WITH ALL WEAK TERMS ?
YES
FORM STIFFNESS MATRIX BY ADDING STIFFNESS MATRICES OF ALL WEAK TERMS
2556
STOP
NO
2554
CURRENT_WEAK_TERM = NEXT WEAK TERM SUM = 0
2558
DONE WITH ALL EVALUATION POINTS ?
YES
2568
i = i + 1 WEAK_TERM_STIFFNESS _MATRIX[i] = SUM
NO
2560
P = NEXT SET OF EVALUATION POINTS
JACOB_V = COMPUTE_JACOBIAN_OF _VAR V AT THE POINTS P
2562
JACOB_W = COMPUTE_JACOBIAN_OF _VAR W AT THE POINTS P
2564
SUM = SUM + JACOB_V * JACOB_W *(WEIGHTS OF POINTS P)
2566

FIG. 52

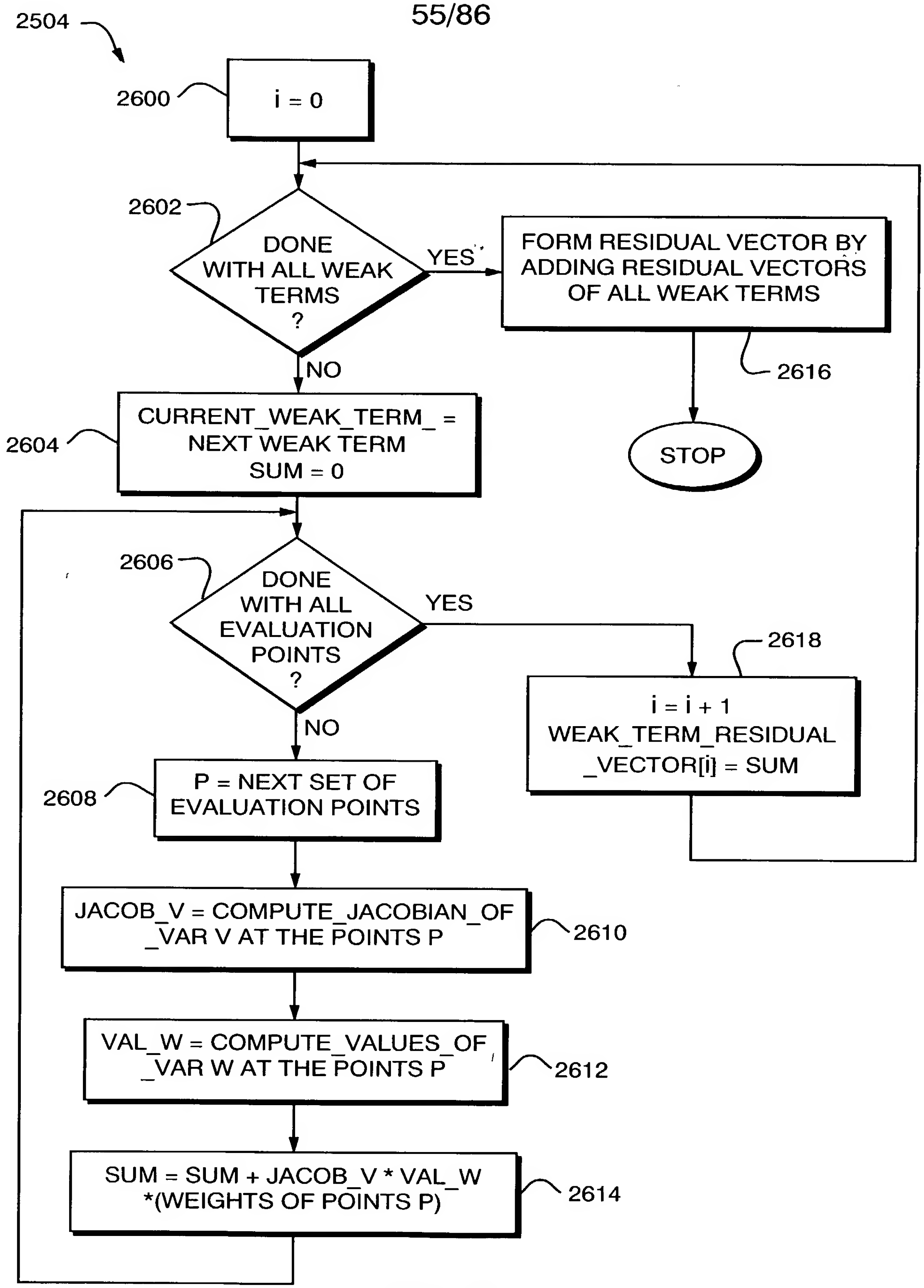
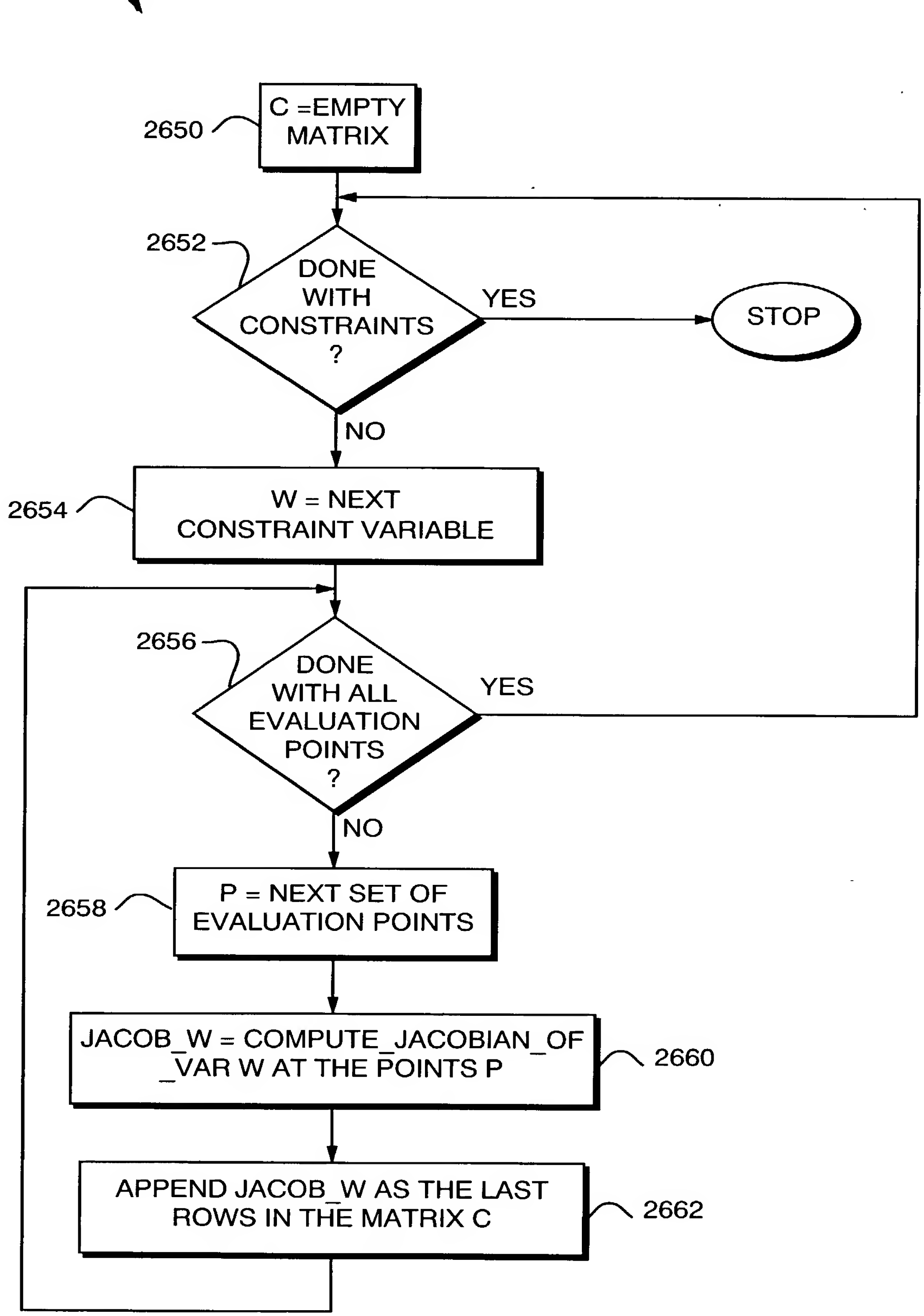

2504
2600
i = 0
2602
DONE WITH ALL WEAK TERMS ?
YES
FORM RESIDUAL VECTOR BY ADDING RESIDUAL VECTORS OF ALL WEAK TERMS
2616
STOP
NO
2604
CURRENT_WEAK_TERM_ = NEXT WEAK TERM
SUM = 0
2606
DONE WITH ALL EVALUATION POINTS ?
YES
2618
i = i + 1
WEAK_TERM_RESIDUAL _VECTOR[i] = SUM
NO
2608
P = NEXT SET OF EVALUATION POINTS
JACOB_V = COMPUTE_JACOBIAN_OF _VAR V AT THE POINTS P
2610
VAL_W = COMPUTE_VALUES_OF _VAR W AT THE POINTS P
2612
SUM = SUM + JACOB_V * VAL_W *(WEIGHTS OF POINTS P)
2614

FIG. 53

2506



C =EMPTY MATRIX
2650
DONE WITH CONSTRAINTS ?
2652
YES
STOP
NO
W = NEXT CONSTRAINT VARIABLE
2654
DONE WITH ALL EVALUATION POINTS ?
2656
YES
NO
P = NEXT SET OF EVALUATION POINTS
2658
JACOB_W = COMPUTE_JACOBIAN_OF _VAR W AT THE POINTS P
2660
APPEND JACOB_W AS THE LAST ROWS IN THE MATRIX C
2662

FIG. 54

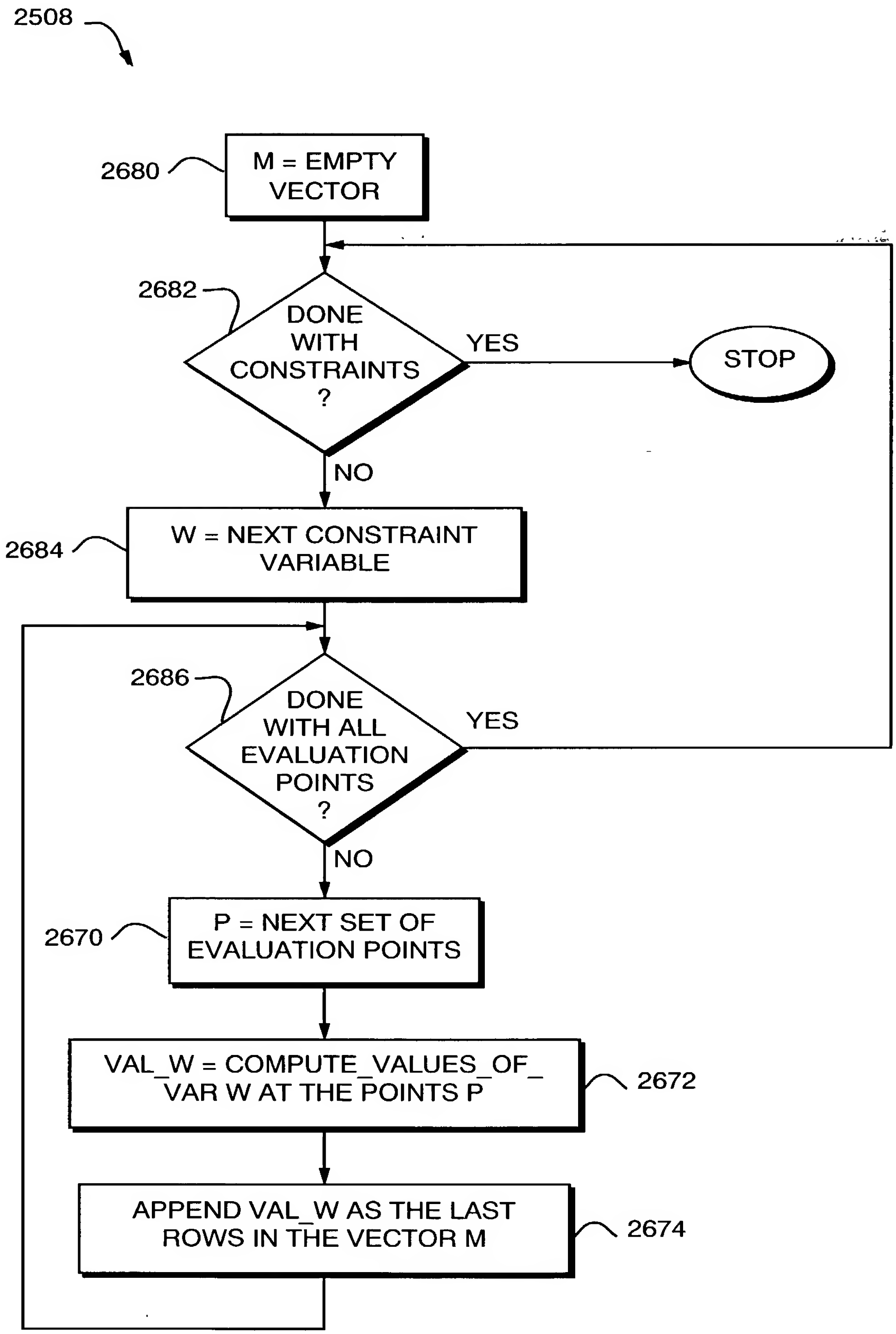

2508
2680
M = EMPTY VECTOR
2682
DONE WITH CONSTRAINTS ?
YES
STOP
NO
2684
W = NEXT CONSTRAINT VARIABLE
2686
DONE WITH ALL EVALUATION POINTS ?
YES
NO
2670
P = NEXT SET OF EVALUATION POINTS
VAL_W = COMPUTE_VALUES_OF_VAR W AT THE POINTS P
2672
APPEND VAL_W AS THE LAST ROWS IN THE VECTOR M
2674

FIG. 55A

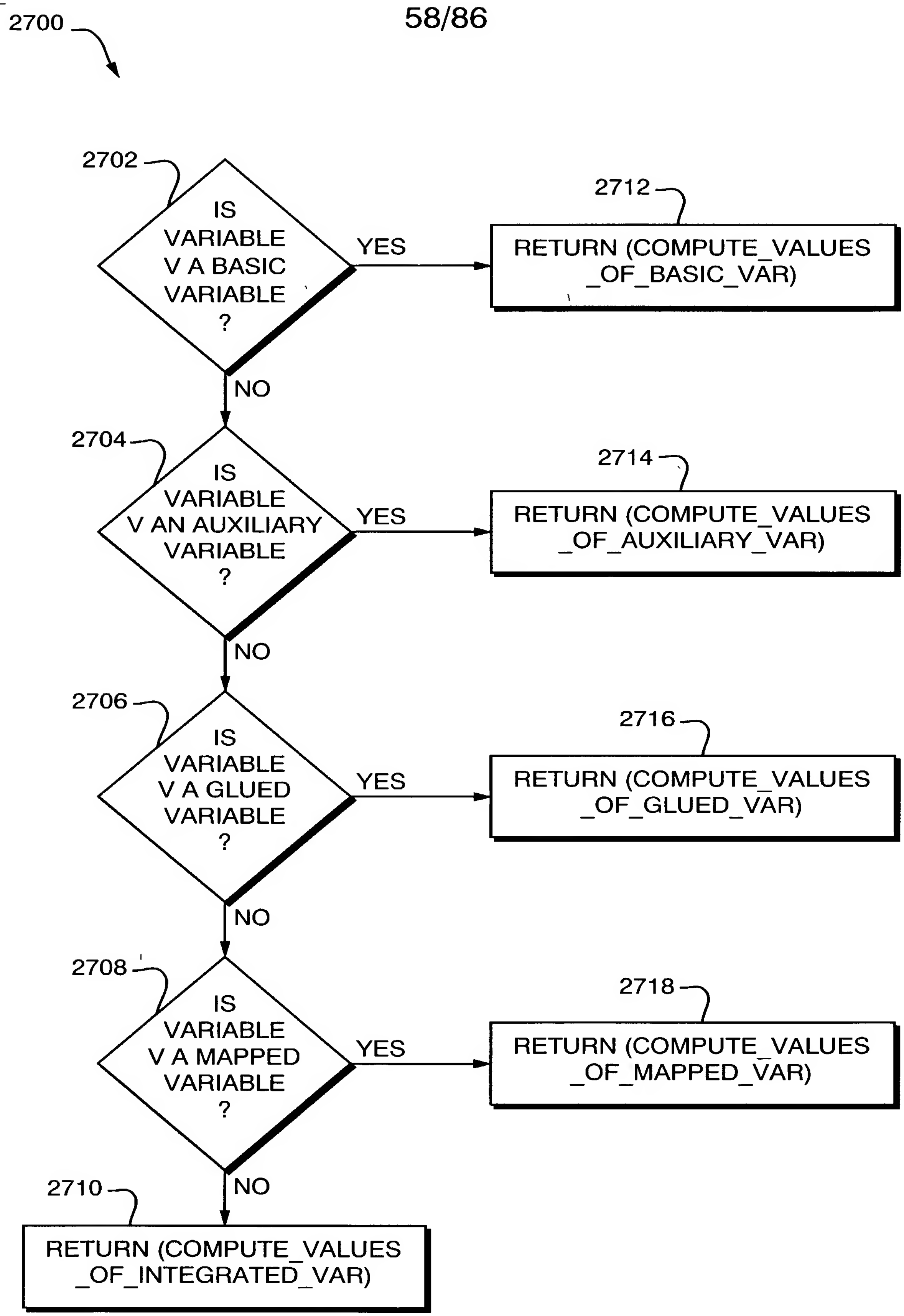

2700
2702
IS VARIABLE V A BASIC VARIABLE ?
YES
2712
RETURN (COMPUTE_VALUES _OF_BASIC_VAR)
NO
2704
IS VARIABLE V AN AUXILIARY VARIABLE ?
YES
2714
RETURN (COMPUTE_VALUES _OF_AUXILIARY_VAR)
NO
2706
IS VARIABLE V A GLUED VARIABLE ?
YES
2716
RETURN (COMPUTE_VALUES _OF_GLUED_VAR)
NO
2708
IS VARIABLE V A MAPPED VARIABLE ?
YES
2718
RETURN (COMPUTE_VALUES _OF_MAPPED_VAR)
NO
2710
RETURN (COMPUTE_VALUES _OF_INTEGRATED_VAR)

FIG. 55B

2720

RETURN THE SUMS $\sum Ui * Fi(pj)$, WHERE THE SUM IS TAKEN OVER ALL INDICES i OF THE DEGREES OF FREEDOM, FOR pj IN THE SET P

FIG. 55C

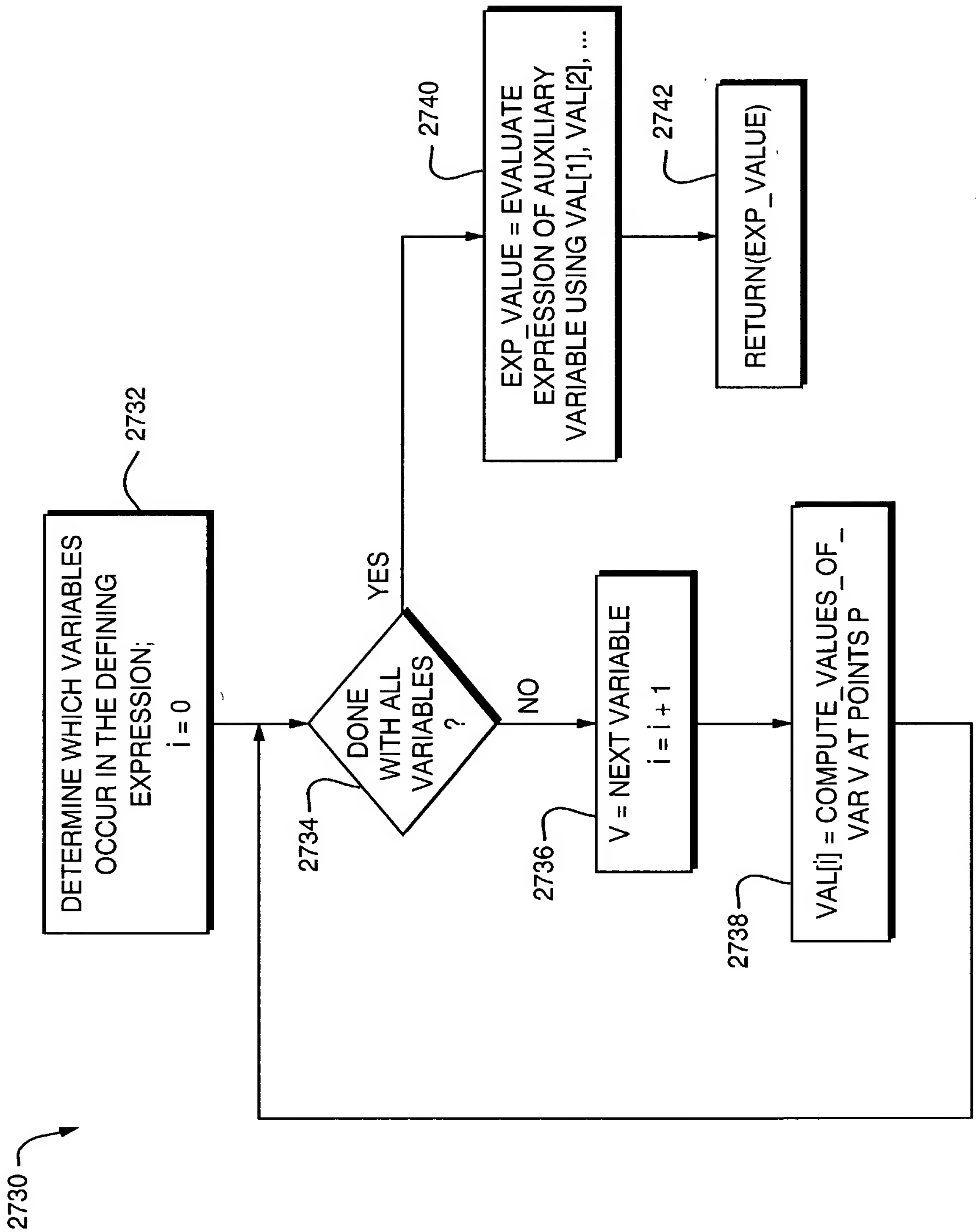

2730
DETERMINE WHICH VARIABLES OCCUR IN THE DEFINING EXPRESSION; i = 0
2732
DONE WITH ALL VARIABLES ?
2734
YES
NO
V = NEXT VARIABLE i = i + 1
2736
VAL[i] = COMPUTE_VALUES_OF_VAR V AT POINTS P
2738
EXP_VALUE = EVALUATE EXPRESSION OF AUXILIARY VARIABLE USING VAL[1], VAL[2], ...
2740
RETURN(EXP_VALUE)
2742

FIG. 55D

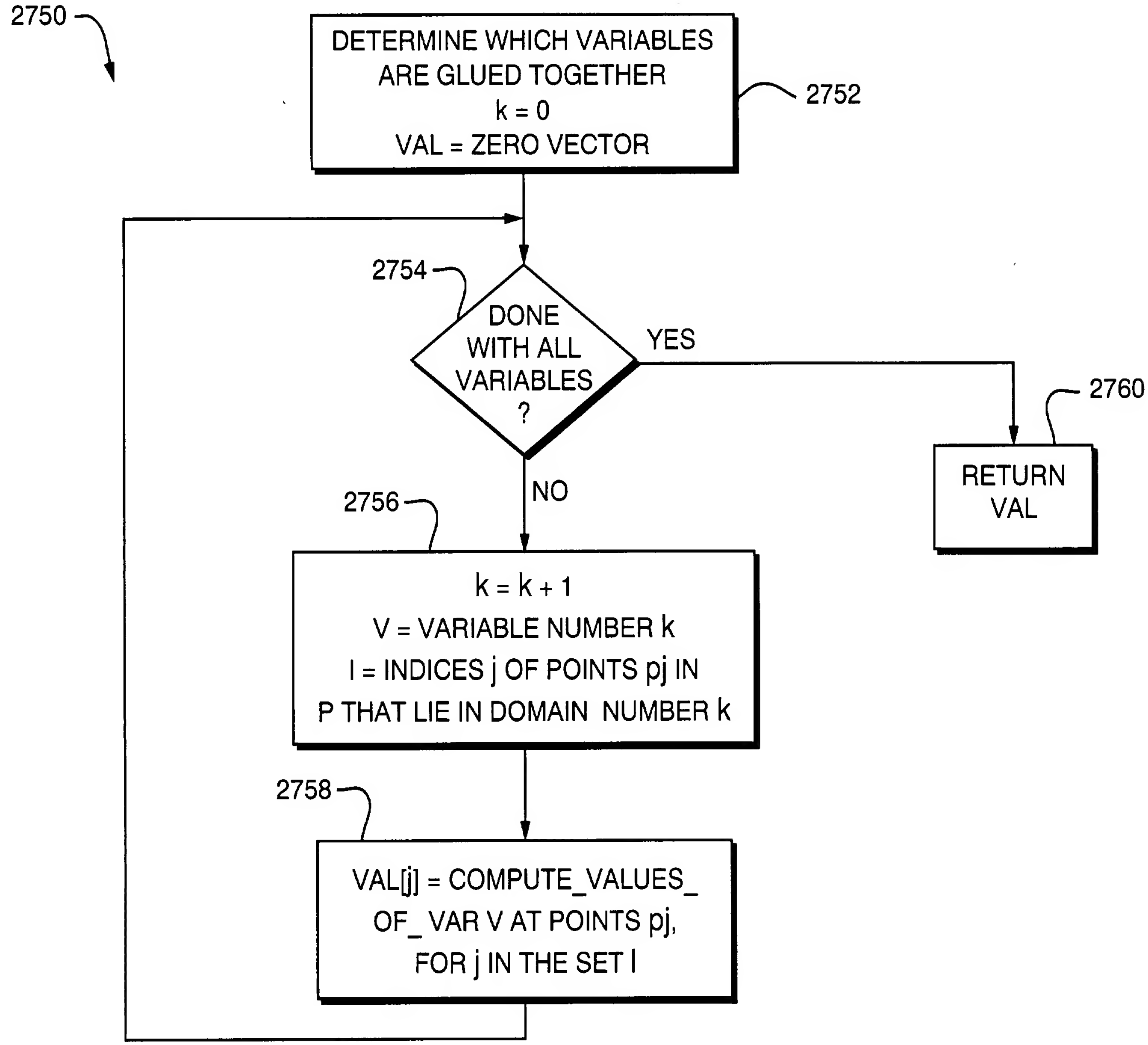

2750
DETERMINE WHICH VARIABLES ARE GLUED TOGETHER
k = 0
VAL = ZERO VECTOR
2752
2754
DONE WITH ALL VARIABLES ?
YES
NO
2760
RETURN VAL
2756
k = k + 1
V = VARIABLE NUMBER k
I = INDICES j OF POINTS pj IN P THAT LIE IN DOMAIN NUMBER k
2758
VAL[j] = COMPUTE_VALUES_OF_ VAR V AT POINTS pj, FOR j IN THE SET I

FIG. 55E

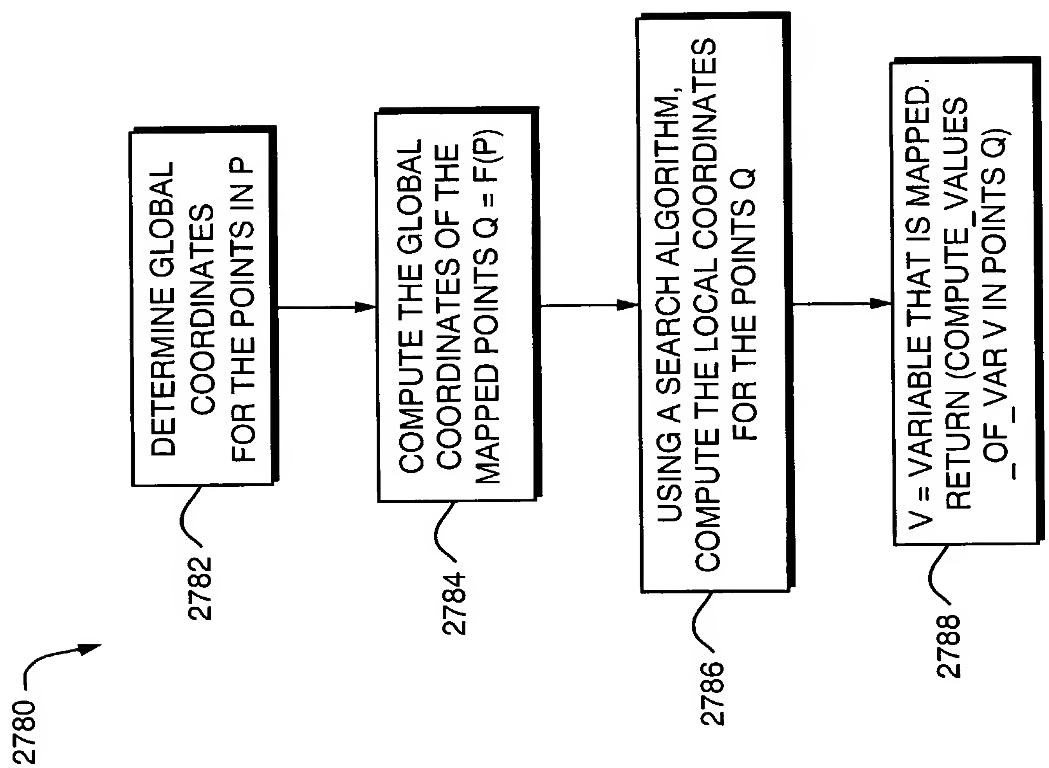

2780
DETERMINE GLOBAL COORDINATES FOR THE POINTS IN P
2782
COMPUTE THE GLOBAL COORDINATES OF THE MAPPED POINTS Q = F(P)
2784
USING A SEARCH ALGORITHM, COMPUTE THE LOCAL COORDINATES FOR THE POINTS Q
2786
V = VARIABLE THAT IS MAPPED. RETURN (COMPUTE_VALUES_OF_VAR V IN POINTS Q)
2788

FIG. 55F

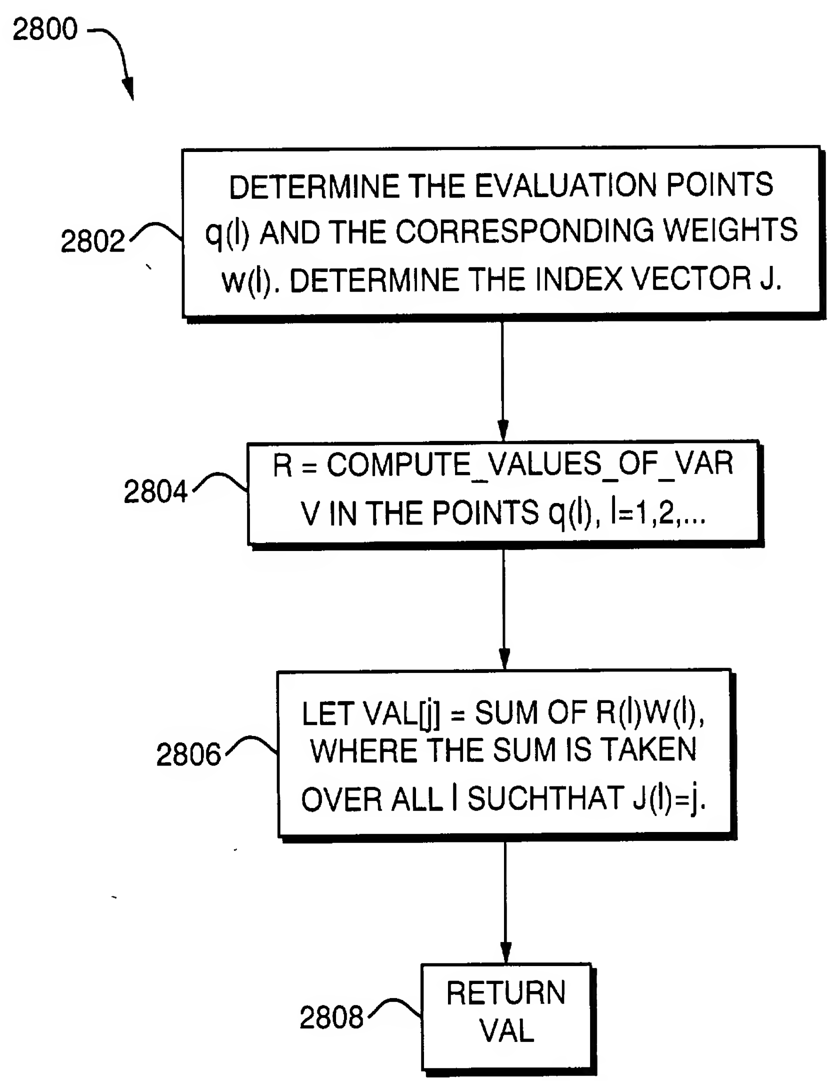

2800
2802
DETERMINE THE EVALUATION POINTS q(l) AND THE CORRESPONDING WEIGHTS w(l). DETERMINE THE INDEX VECTOR J.
2804
R = COMPUTE_VALUES_OF_VAR V IN THE POINTS q(l), l=1,2,...
2806
LET VAL[j] = SUM OF R(l)W(l), WHERE THE SUM IS TAKEN OVER ALL l SUCHTHAT J(l)=j.
2808
RETURN VAL

FIG. 55G

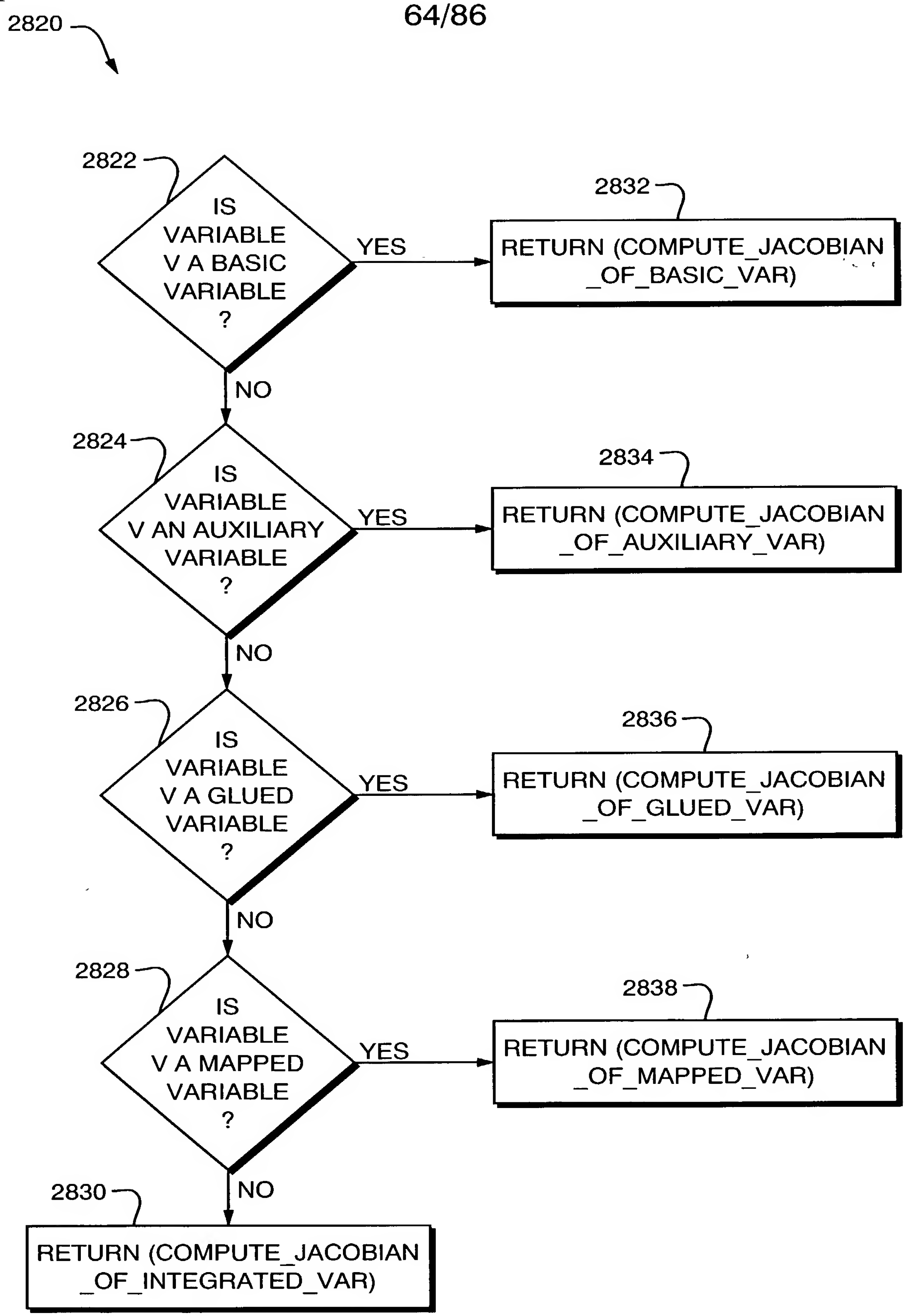

2820
2822
IS VARIABLE V A BASIC VARIABLE ?
YES
2832
RETURN (COMPUTE_JACOBIAN _OF_BASIC_VAR)
NO
2824
IS VARIABLE V AN AUXILIARY VARIABLE ?
YES
2834
RETURN (COMPUTE_JACOBIAN _OF_AUXILIARY_VAR)
NO
2826
IS VARIABLE V A GLUED VARIABLE ?
YES
2836
RETURN (COMPUTE_JACOBIAN _OF_GLUED_VAR)
NO
2828
IS VARIABLE V A MAPPED VARIABLE ?
YES
2838
RETURN (COMPUTE_JACOBIAN _OF_MAPPED_VAR)
NO
2830
RETURN (COMPUTE_JACOBIAN _OF_INTEGRATED_VAR)

FIG. 55H

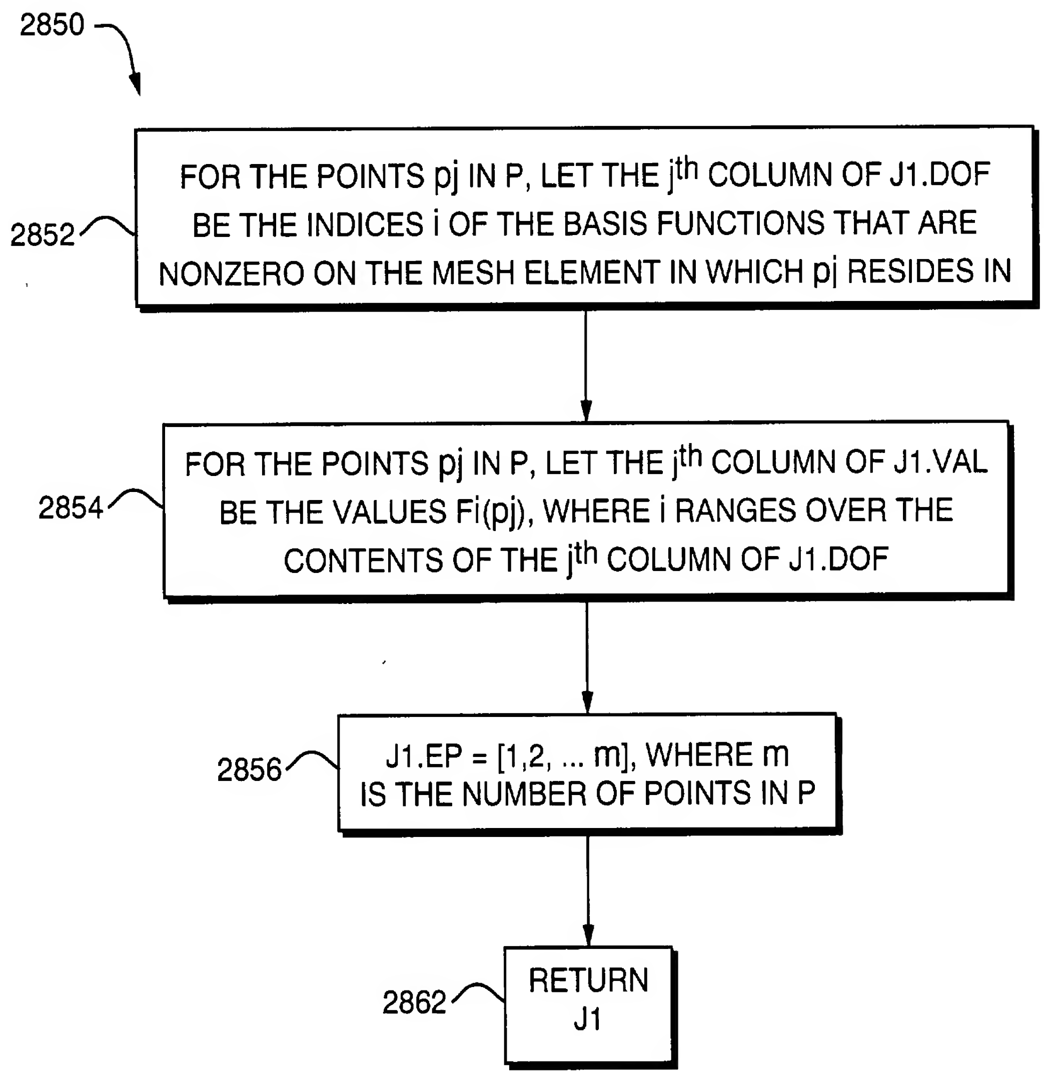

2850
2852
FOR THE POINTS pj IN P, LET THE jth COLUMN OF J1.DOF BE THE INDICES i OF THE BASIS FUNCTIONS THAT ARE NONZERO ON THE MESH ELEMENT IN WHICH pj RESIDES IN
2854
FOR THE POINTS pj IN P, LET THE jth COLUMN OF J1.VAL BE THE VALUES Fi(pj), WHERE i RANGES OVER THE CONTENTS OF THE jth COLUMN OF J1.DOF
2856
J1.EP = [1,2, ... m], WHERE m IS THE NUMBER OF POINTS IN P
2862
RETURN J1

FIG. 55I

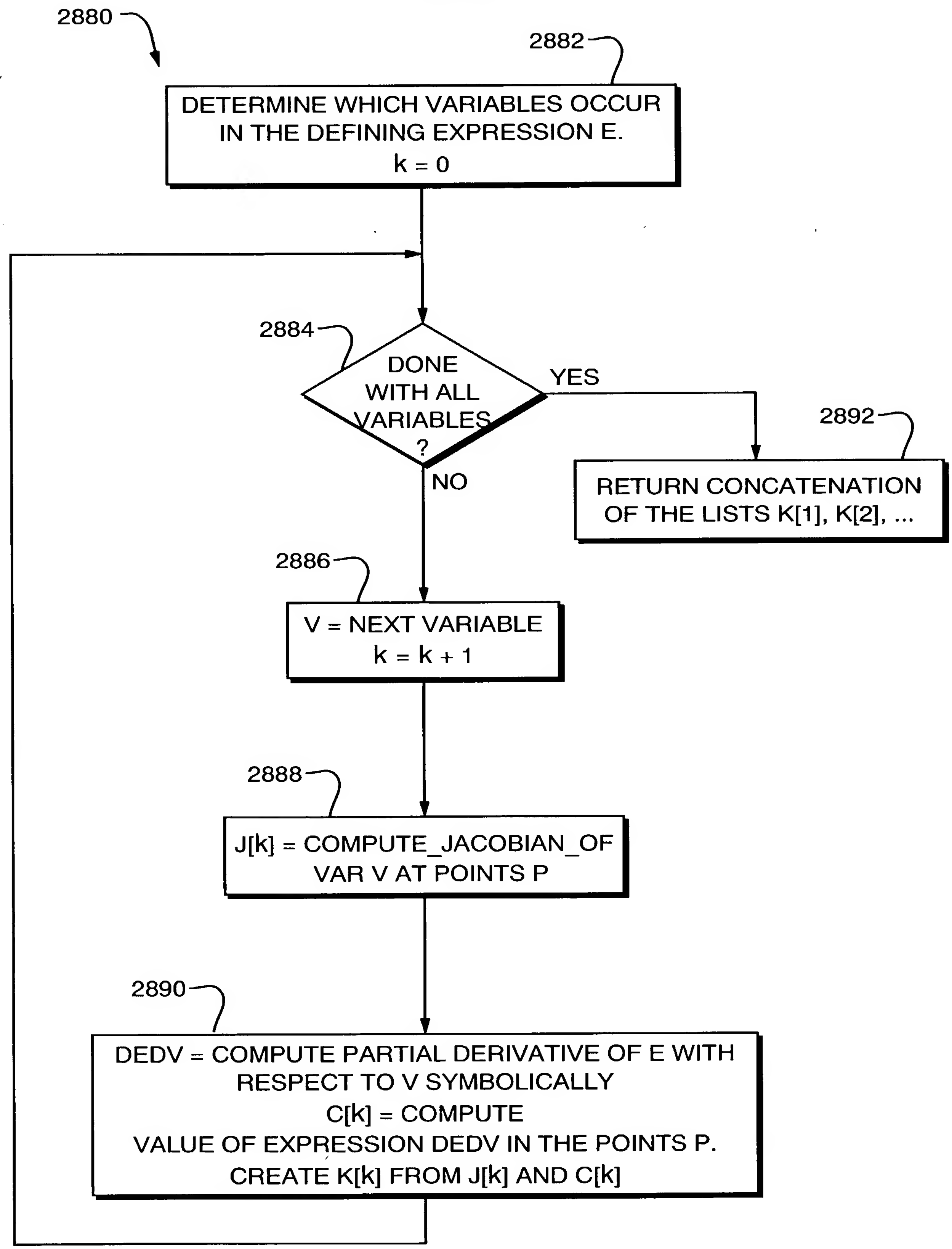

2880
2882
DETERMINE WHICH VARIABLES OCCUR IN THE DEFINING EXPRESSION E.
k = 0
2884
DONE WITH ALL VARIABLES ?
YES
NO
2892
RETURN CONCATENATION OF THE LISTS K[1], K[2], ...
2886
V = NEXT VARIABLE
k = k + 1
2888
J[k] = COMPUTE_JACOBIAN_OF VAR V AT POINTS P
2890
DEDV = COMPUTE PARTIAL DERIVATIVE OF E WITH RESPECT TO V SYMBOLICALLY
C[k] = COMPUTE
VALUE OF EXPRESSION DEDV IN THE POINTS P.
CREATE K[k] FROM J[k] AND C[k]

FIG. 55J

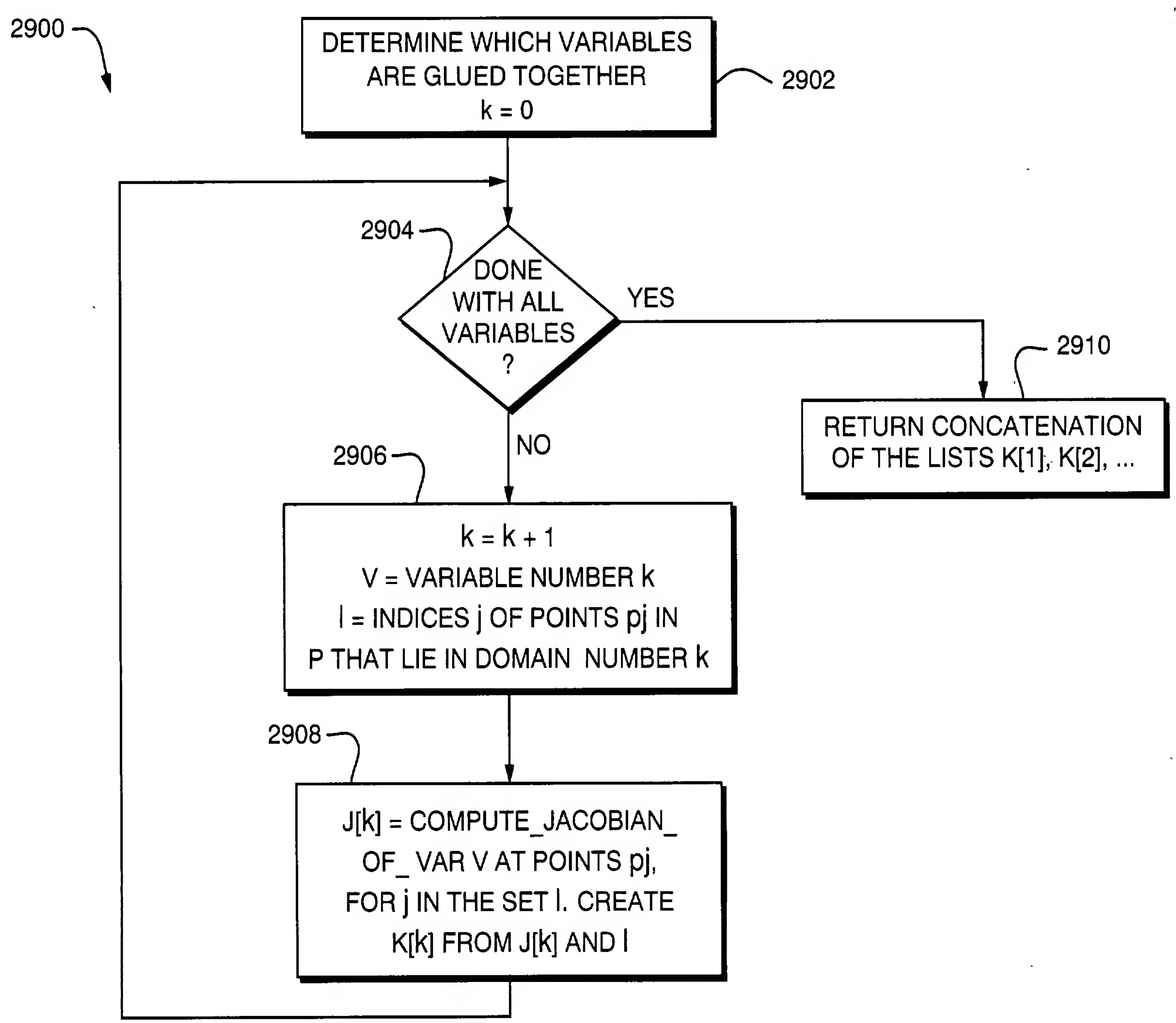

2900
DETERMINE WHICH VARIABLES ARE GLUED TOGETHER k = 0
2902
2904
DONE WITH ALL VARIABLES ?
YES
NO
2910
RETURN CONCATENATION OF THE LISTS K[1], K[2], ...
2906
k = k + 1
V = VARIABLE NUMBER k
I = INDICES j OF POINTS pj IN P THAT LIE IN DOMAIN NUMBER k
2908
J[k] = COMPUTE_JACOBIAN_OF_ VAR V AT POINTS pj, FOR j IN THE SET I. CREATE K[k] FROM J[k] AND I

FIG. 55K

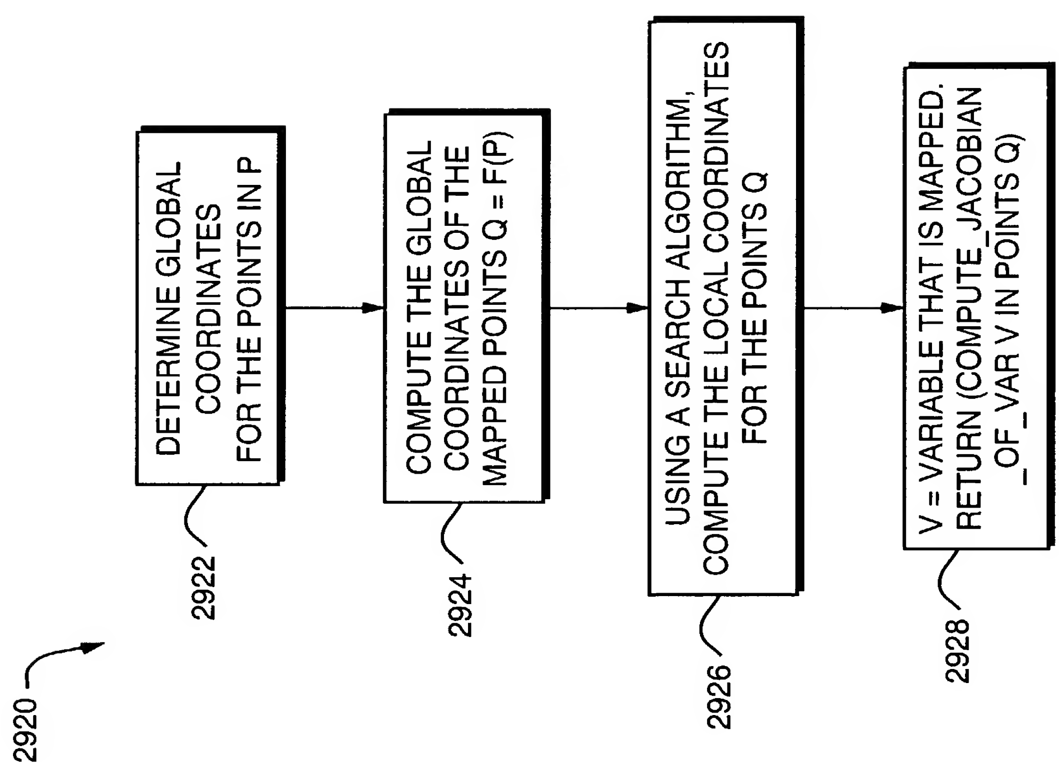

2920
DETERMINE GLOBAL COORDINATES FOR THE POINTS IN P
2922
COMPUTE THE GLOBAL COORDINATES OF THE MAPPED POINTS Q = F(P)
2924
USING A SEARCH ALGORITHM, COMPUTE THE LOCAL COORDINATES FOR THE POINTS Q
2926
V = VARIABLE THAT IS MAPPED. RETURN (COMPUTE_JACOBIAN _OF_VAR V IN POINTS Q)
2928

FIG. 55L

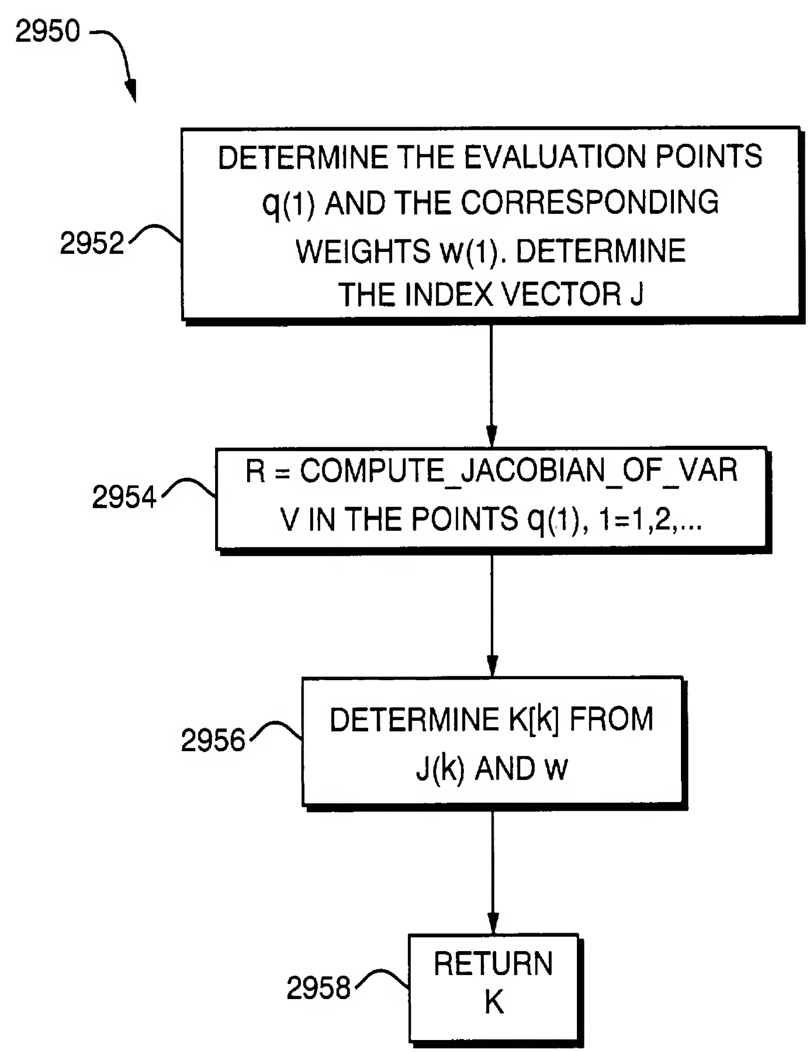

2950
2952
DETERMINE THE EVALUATION POINTS q(1) AND THE CORRESPONDING WEIGHTS w(1). DETERMINE THE INDEX VECTOR J
2954
R = COMPUTE_JACOBIAN_OF_VAR V IN THE POINTS q(1), 1=1,2,...
2956
DETERMINE K[k] FROM J(k) AND w
2958
RETURN K

FIG. 55M

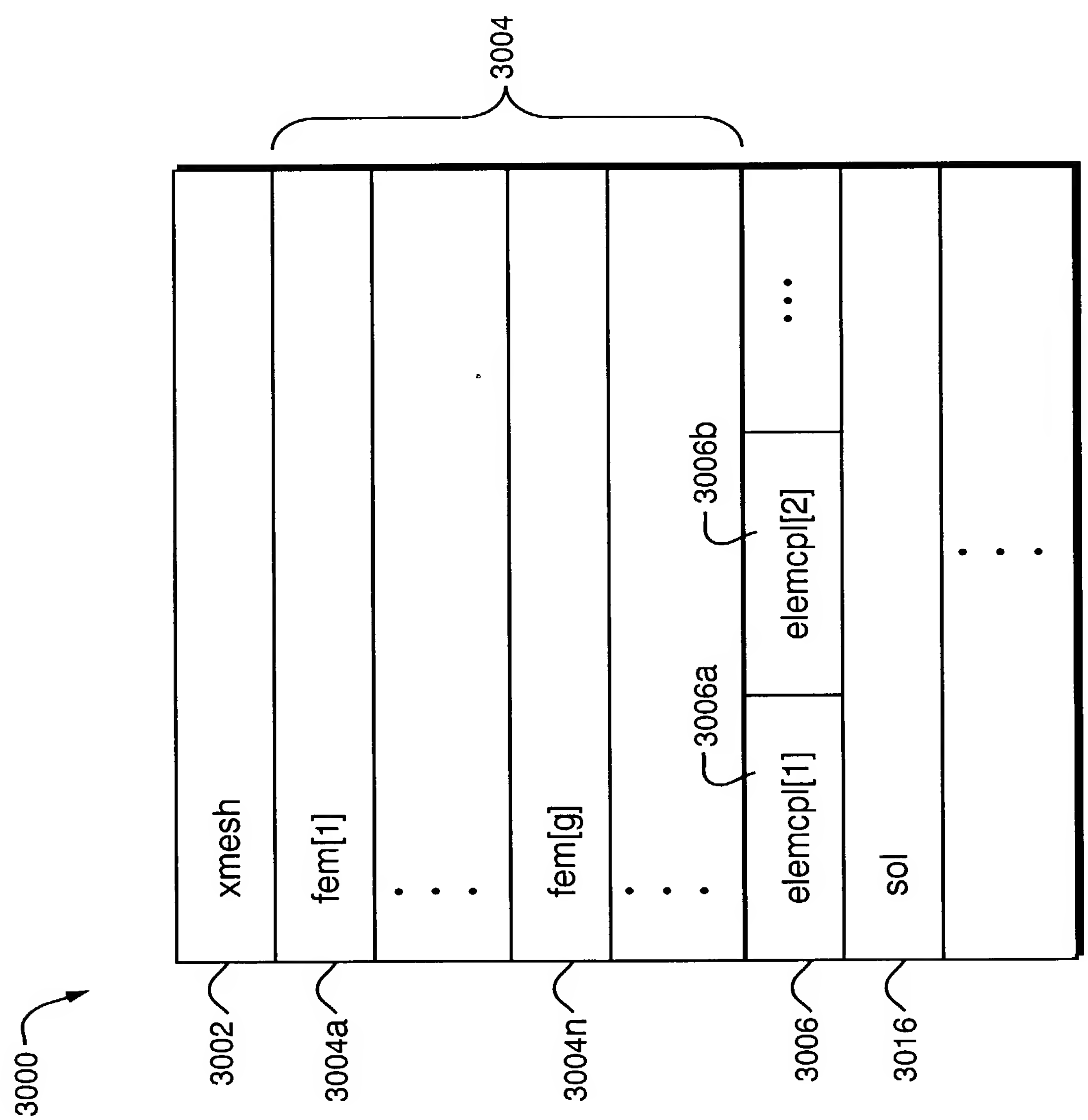

3004
xmesh
fem[1]
. . .
fem[g]
. . .
elemcpl[1]
3006a
elemcpl[2]
3006b
. . .
sol
. . .
3000
3002
3004a
3004n
3006
3016

FIG. 56

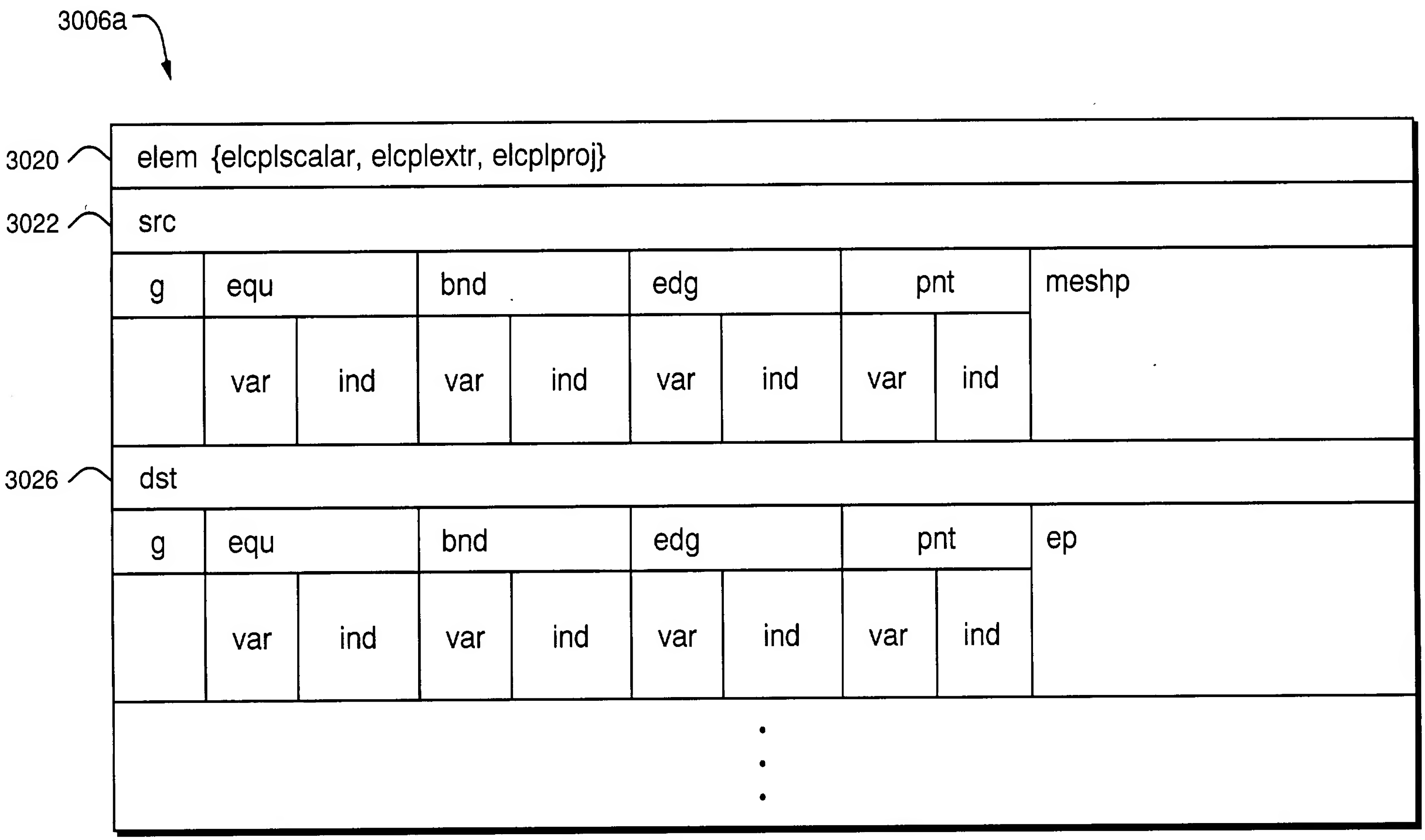

3006a
3020
3022
3026
elem {elcplscalar, elcplextr, elcplproj}
src
g
equ
bnd
edg
pnt
meshp
var
ind
var
ind
var
ind
var
ind
dst
g
equ
bnd
edg
pnt
ep
var
ind
var
ind
var
ind
var
ind

FIG. 57

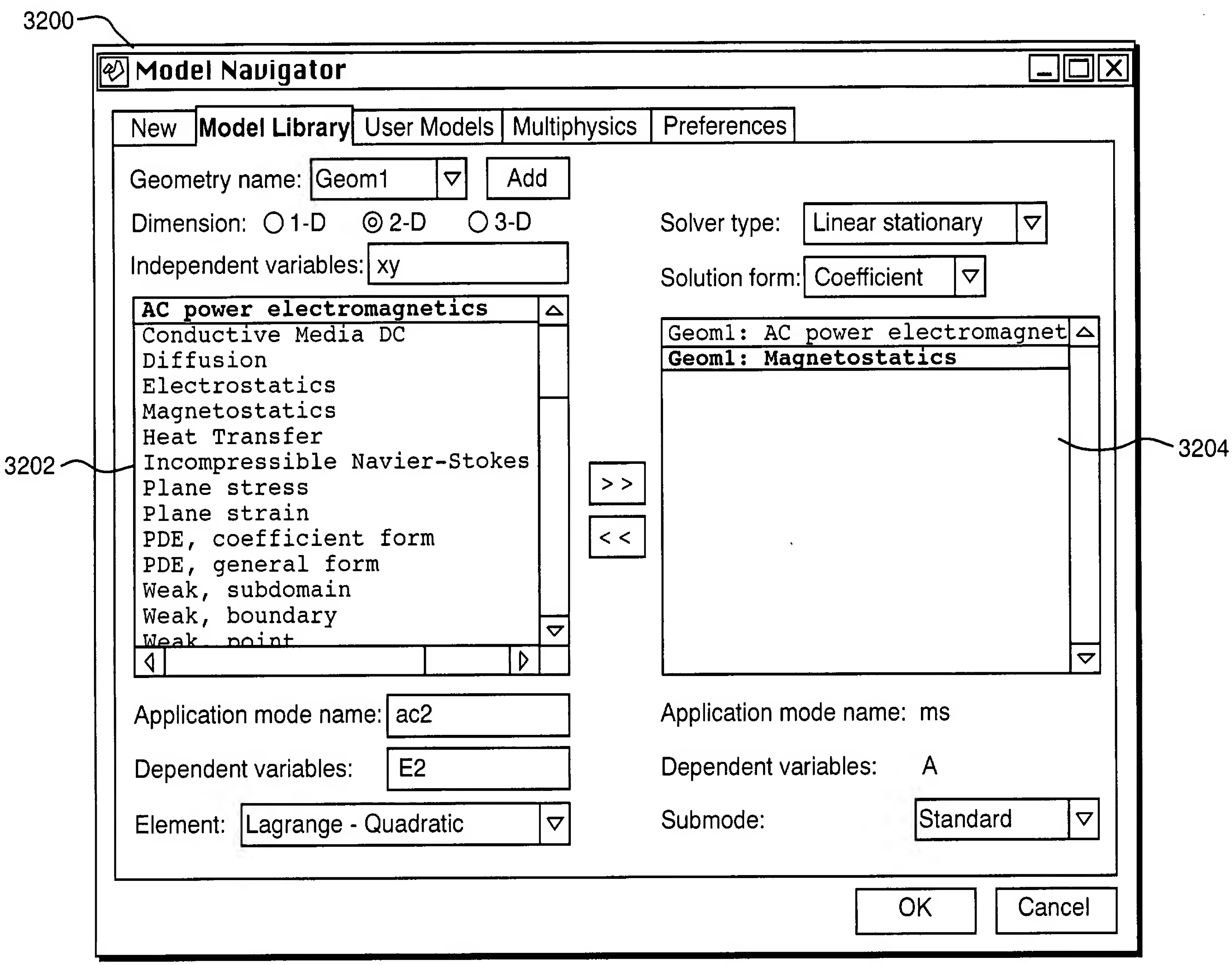
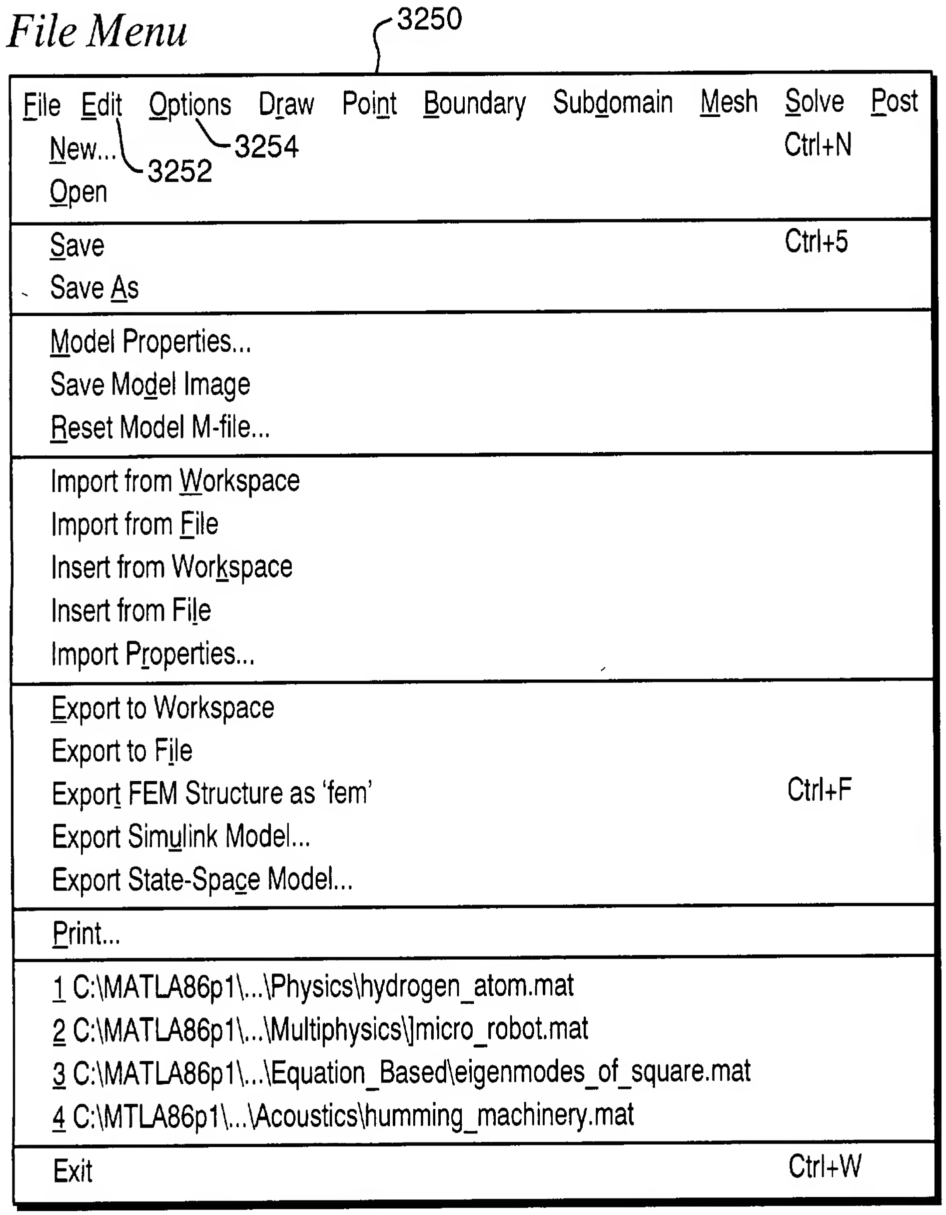
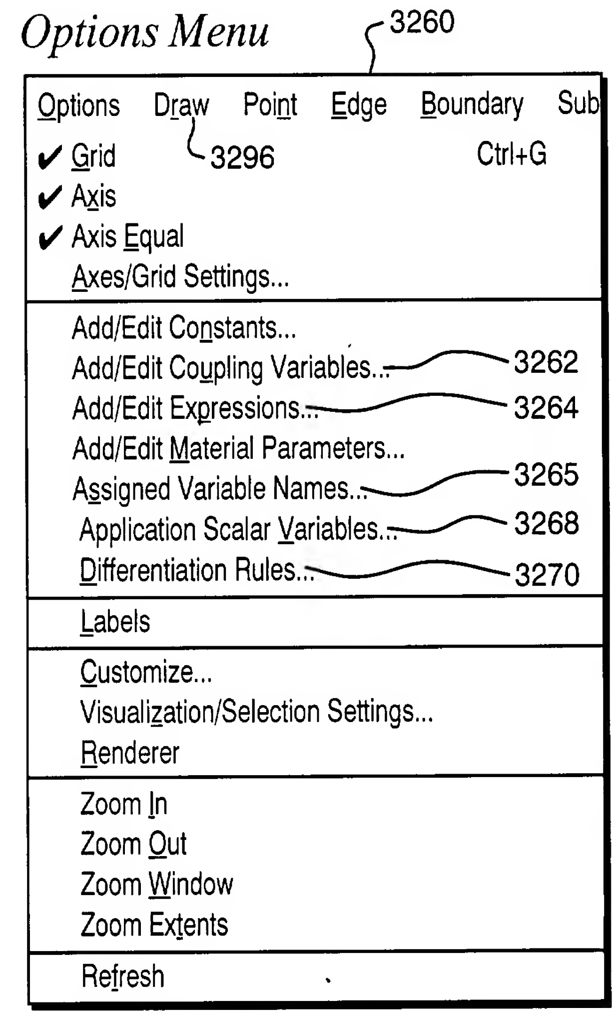

3200
Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Geometry name: Geom1
Add
Dimension: 1-D 2-D 3-D
Independent variables: xy
AC power electromagnetics
Conductive Media DC
Diffusion
Electrostatics
Magnetostatics
Heat Transfer
Incompressible Navier-Stokes
Plane stress
Plane strain
PDE, coefficient form
PDE, general form
Weak, subdomain
Weak, boundary
Weak, point
3202
> >
< <
Solver type: Linear stationary
Solution form: Coefficient
Geom1: AC power electromagnet
Geom1: Magnetostatics
3204
Application mode name: ac2
Dependent variables: E2
Element: Lagrange - Quadratic
Application mode name: ms
Dependent variables: A
Submode: Standard
OK
Cancel

FIG. 58



File Menu
3250
File Edit Options Draw Point Boundary Subdomain Mesh Solve Post
New... 3252 3254 Ctrl+N
Open
Save Ctrl+5
Save As
Model Properties...
Save Model Image
Reset Model M-file...
Import from Workspace
Import from File
Insert from Workspace
Insert from File
Import Properties...
Export to Workspace
Export to File
Export FEM Structure as 'fem' Ctrl+F
Export Simulink Model...
Export State-Space Model...
Print...
1 C:\MATLA86p1\...\Physics\hydrogen_atom.mat
2 C:\MATLA86p1\...\Multiphysics\]micro_robot.mat
3 C:\MATLA86p1\...\Equation_Based\eigenmodes_of_square.mat
4 C:\MTLA86p1\...\Acoustics\humming_machinery.mat
Exit Ctrl+W

FIG. 59



Options Menu
3260
Options Draw Point Edge Boundary Sub
✔ Grid 3296 Ctrl+G
✔ Axis
✔ Axis Equal
Axes/Grid Settings...
Add/Edit Constants...
Add/Edit Coupling Variables... 3262
Add/Edit Expressions... 3264
Add/Edit Material Parameters...
Assigned Variable Names... 3265
Application Scalar Variables... 3268
Differentiation Rules... 3270
Labels
Customize...
Visualization/Selection Settings...
Renderer
Zoom In
Zoom Out
Zoom Window
Zoom Extents
Refresh

FIG. 60

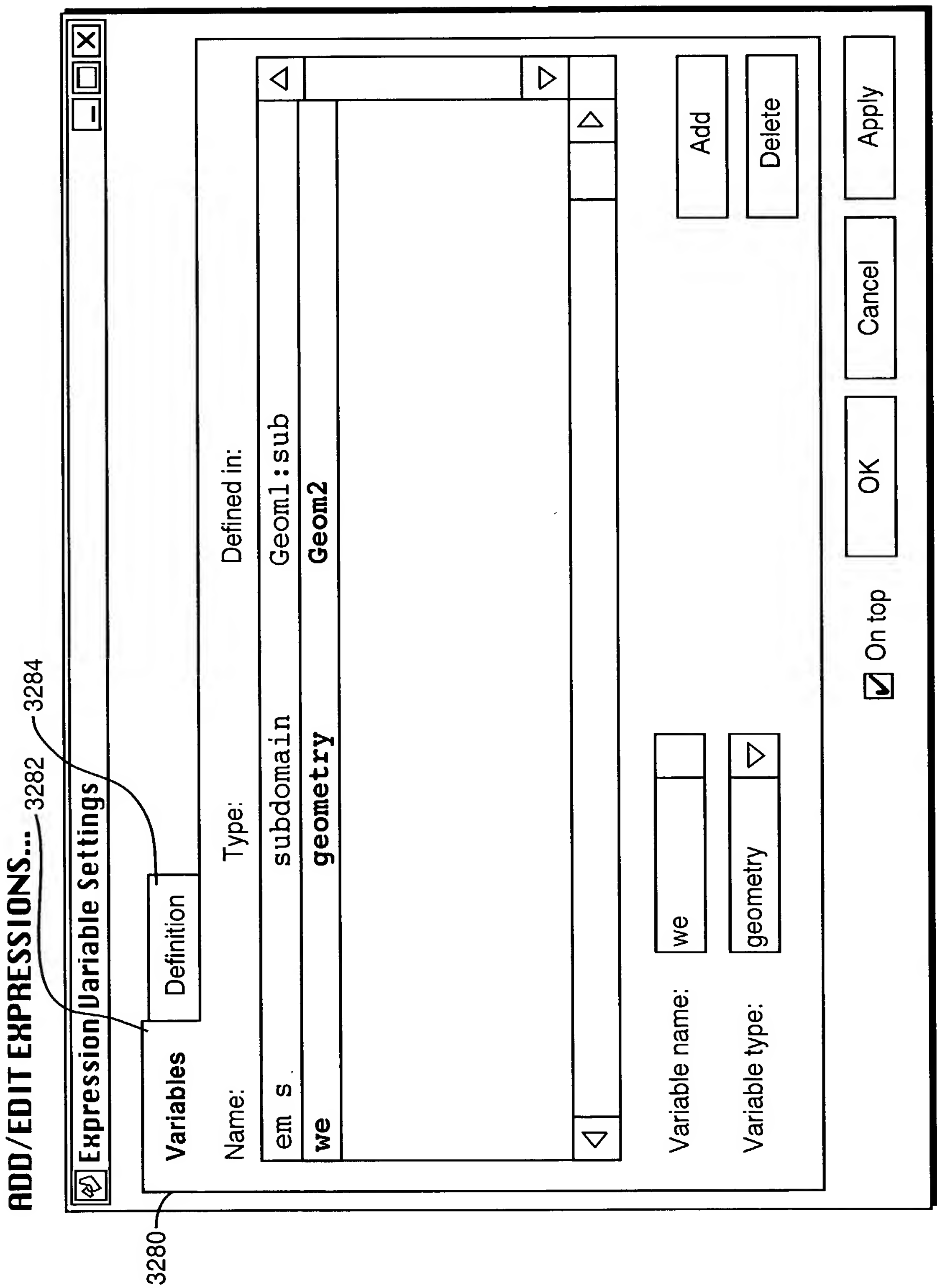

ADD/EDIT EXPRESSIONS...
3282
3284
Expression Variable Settings
Variables
Definition
Name:
Type:
Defined in:
em s
subdomain
Geom1:sub
we
geometry
Geom2
Variable name:
we
Variable type:
geometry
Add
Delete
On top
OK
Cancel
Apply
3280

FIG. 61

ASSIGNED VARIABLE NAMES...

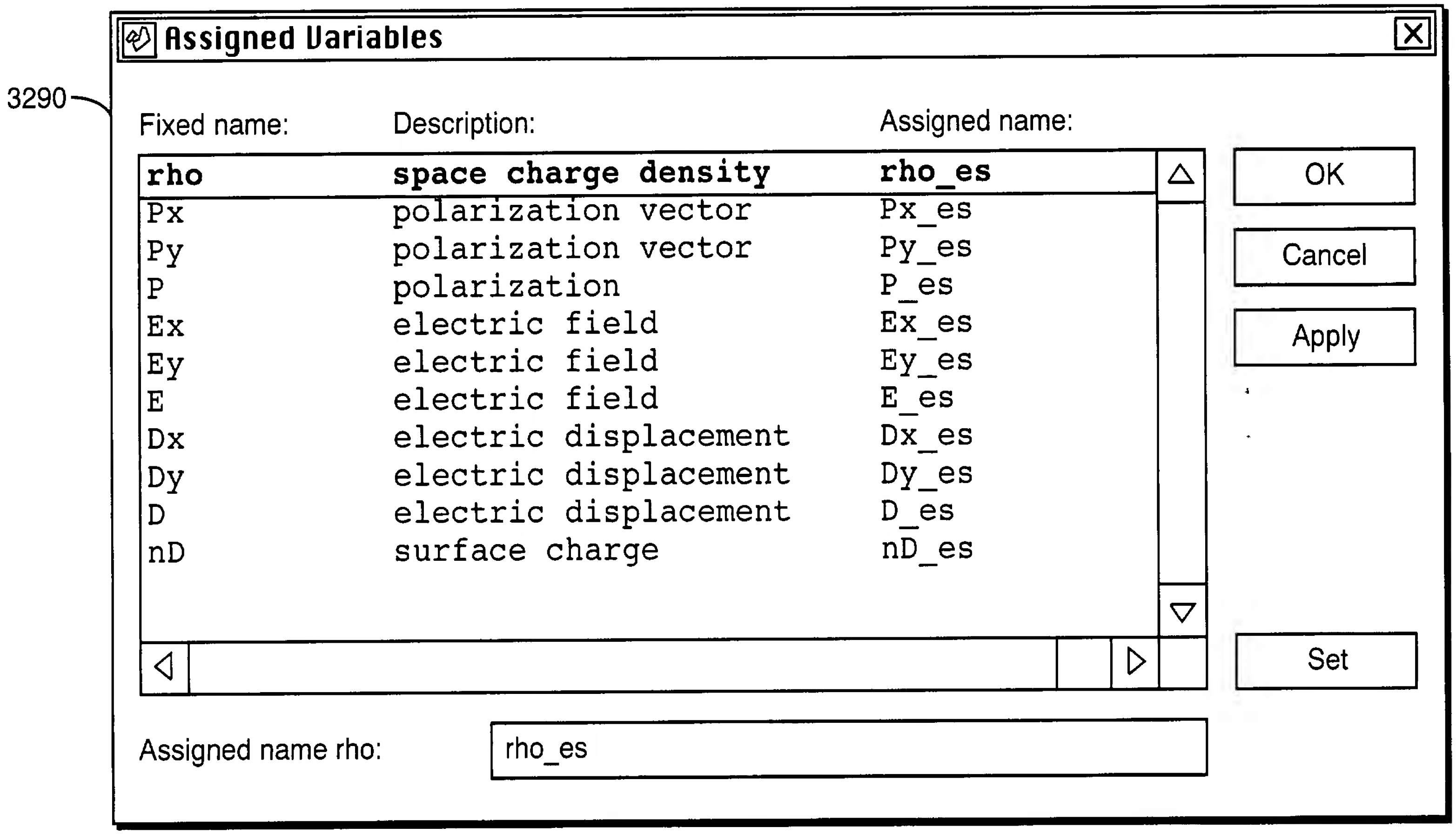


FIG. 62

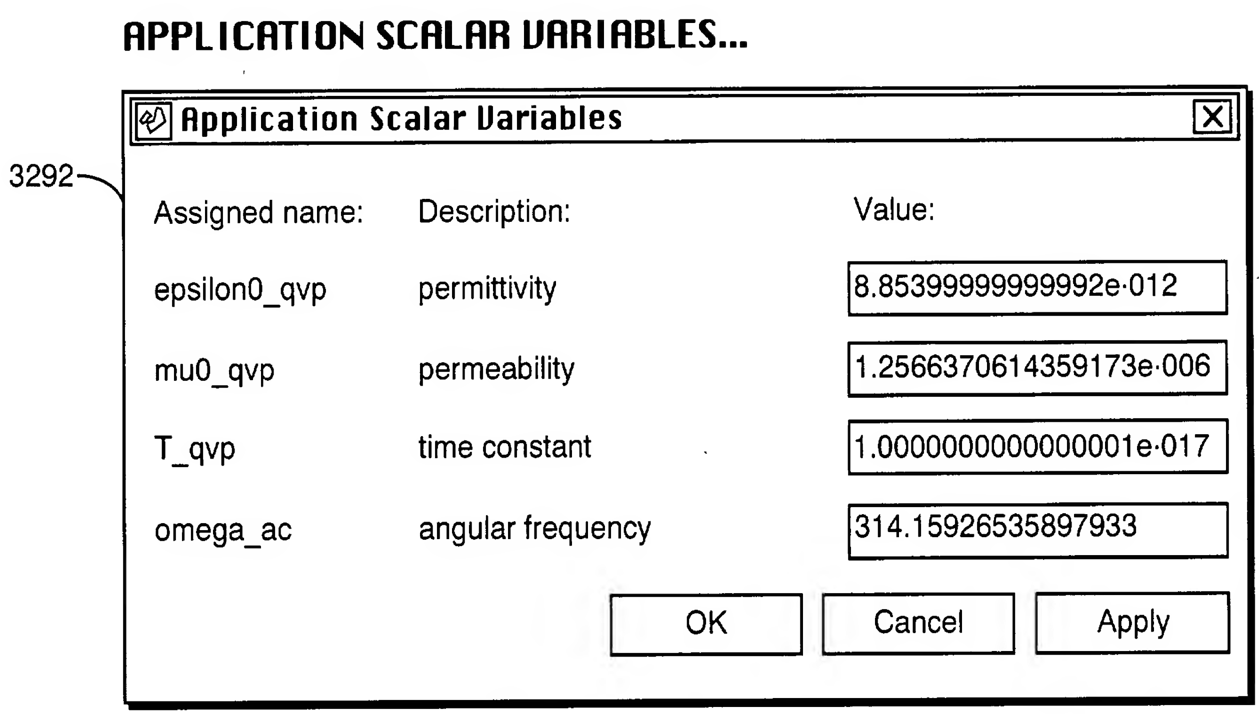

APPLICATION SCALAR VARIABLES...
3292
Application Scalar Variables
Assigned name:
Description:
Value:
epsilon0_qvp
permittivity
8.853999999999992e-012
mu0_qvp
permeability
1.2566370614359173e-006
T_qvp
time constant
1.0000000000000001e-017
omega_ac
angular frequency
314.15926535897933
OK
Cancel
Apply

FIG. 63

DIFFERENTIATION RULES...

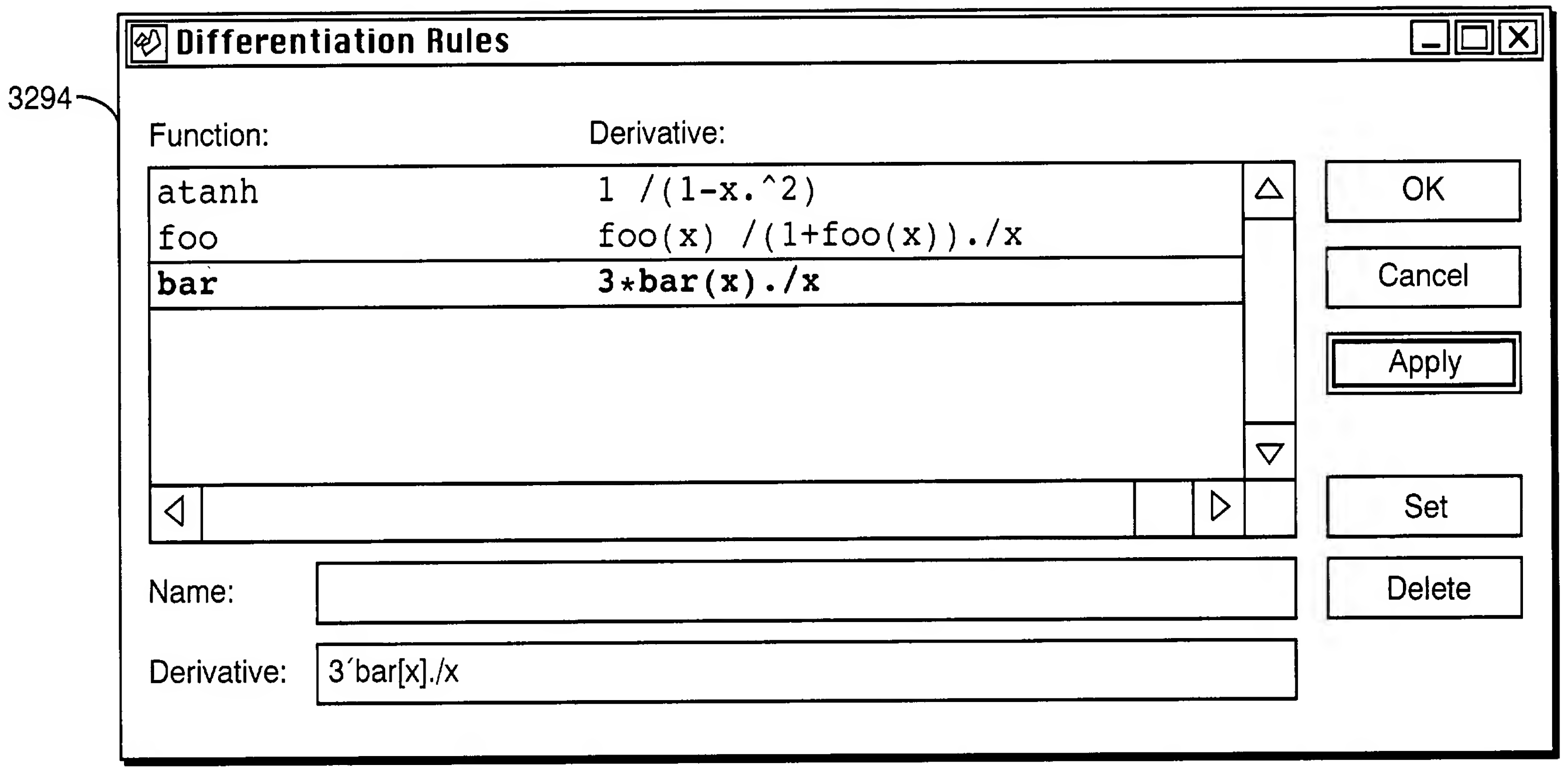


FIG. 64

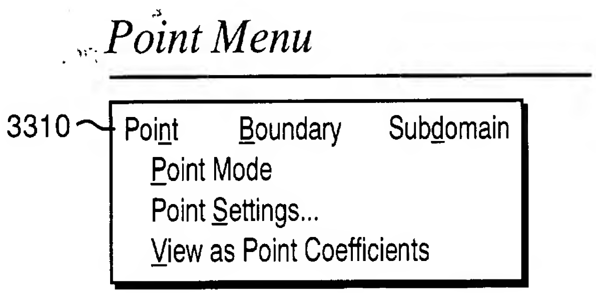


FIG. 65

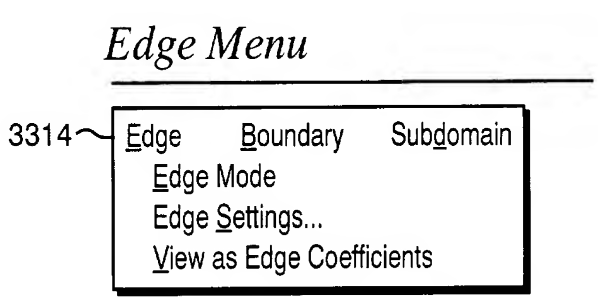


FIG. 67

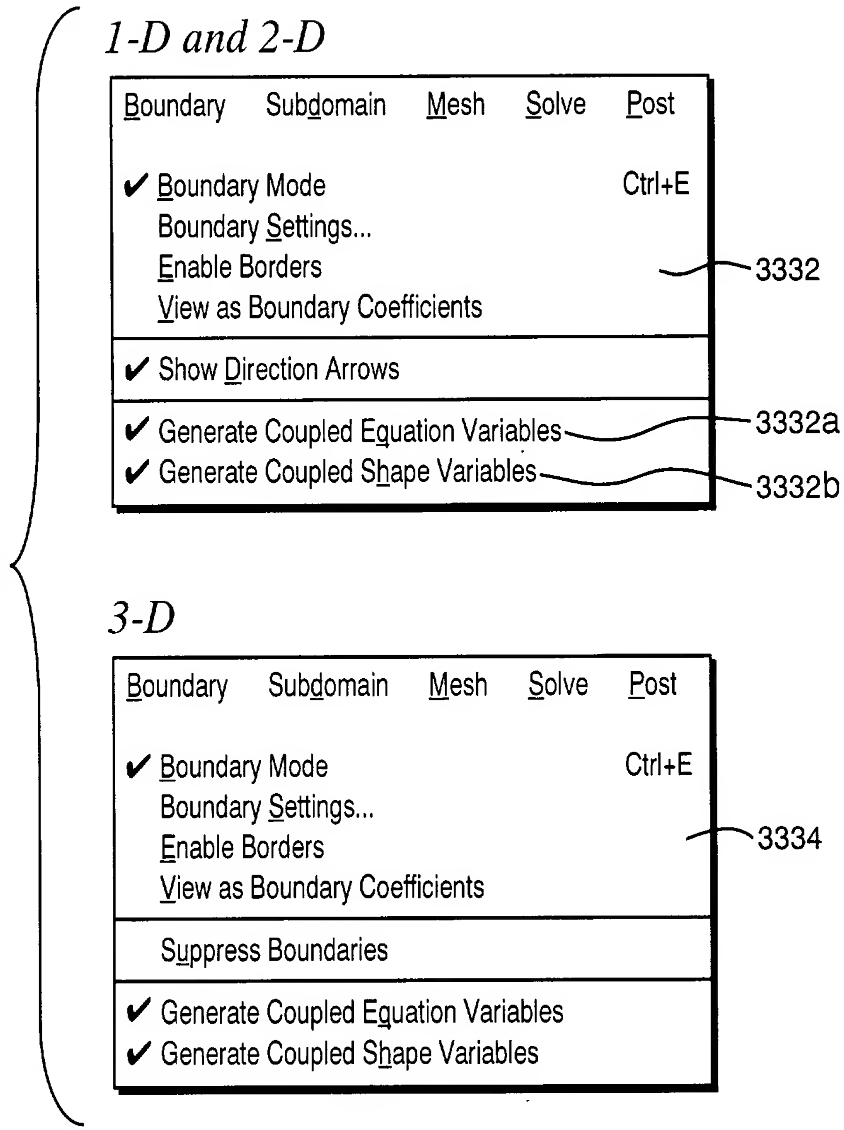


FIG. 69

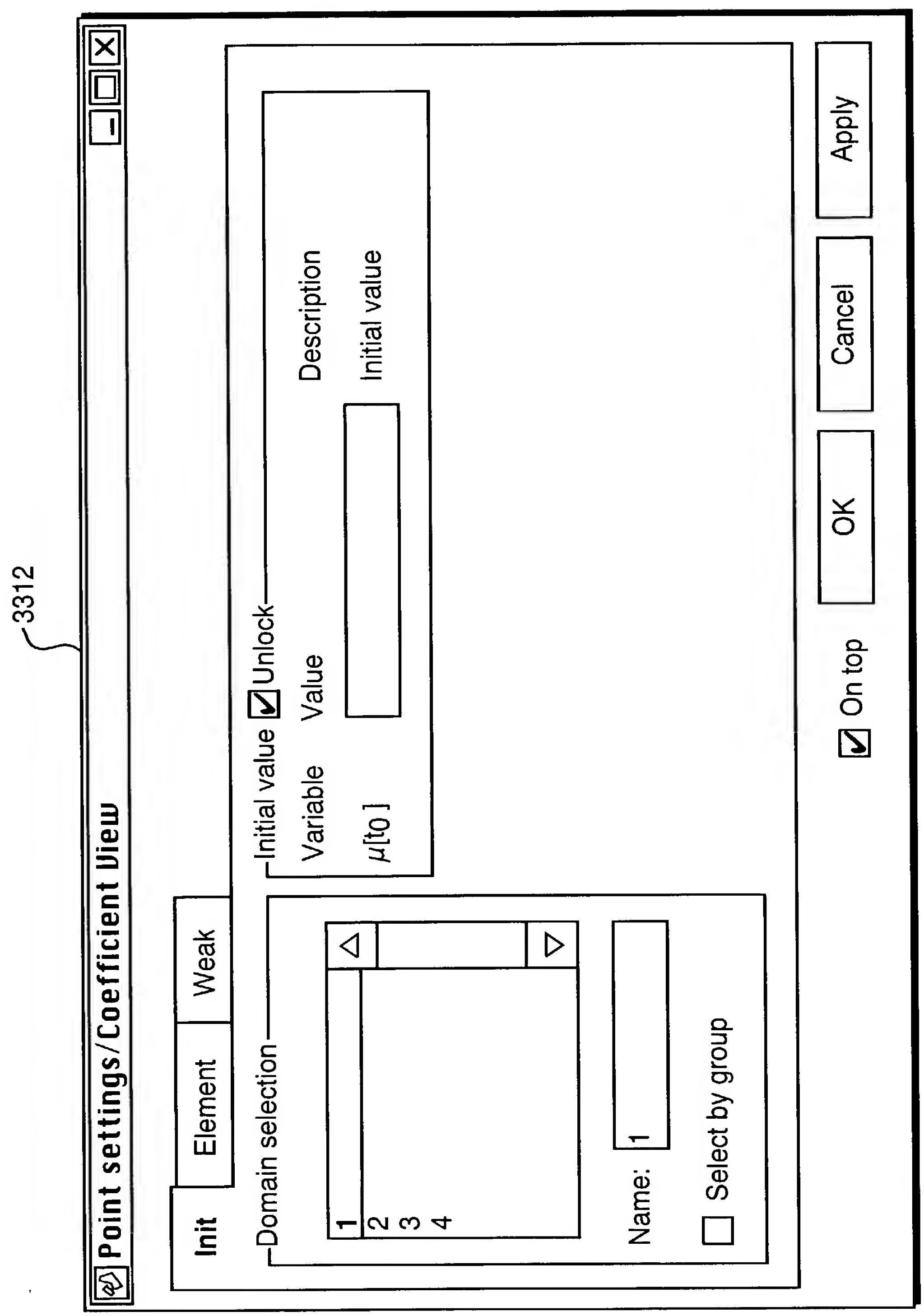

3312
Point settings/Coefficient View
Init
Element
Weak
Domain selection
1
2
3
4
Name:
1
Select by group
Initial value
Unlock
Variable
Value
Description
μ[t0]
Initial value
On top
OK
Cancel
Apply

FIG. 66

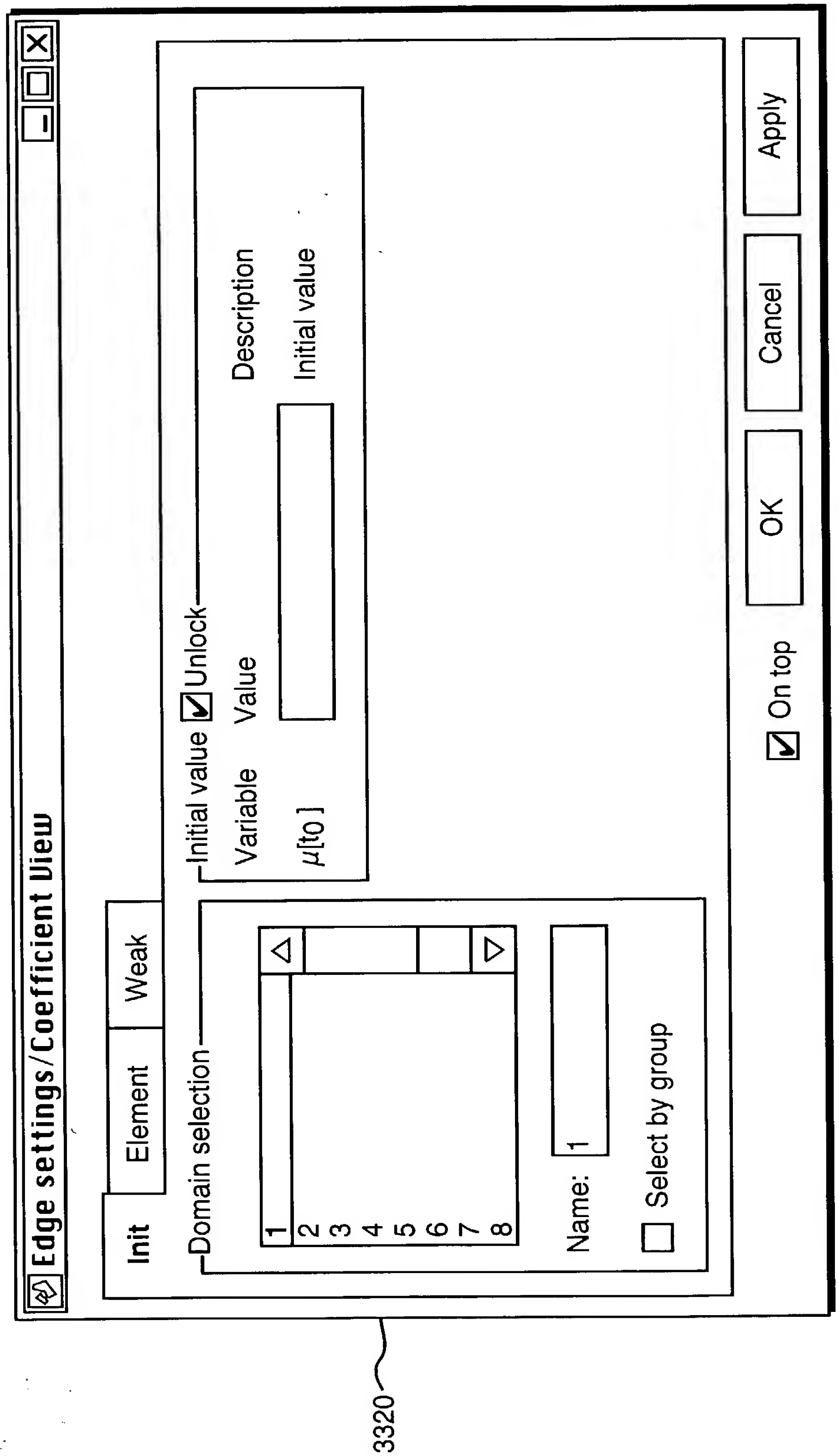

Edge settings/Coefficient View
Init
Element
Weak
Domain selection
1
2
3
4
5
6
7
8
Name:
1
Select by group
Initial value
Unlock
Variable
Value
Description
μ[t0]
Initial value
On top
OK
Cancel
Apply
3320

FIG. 68

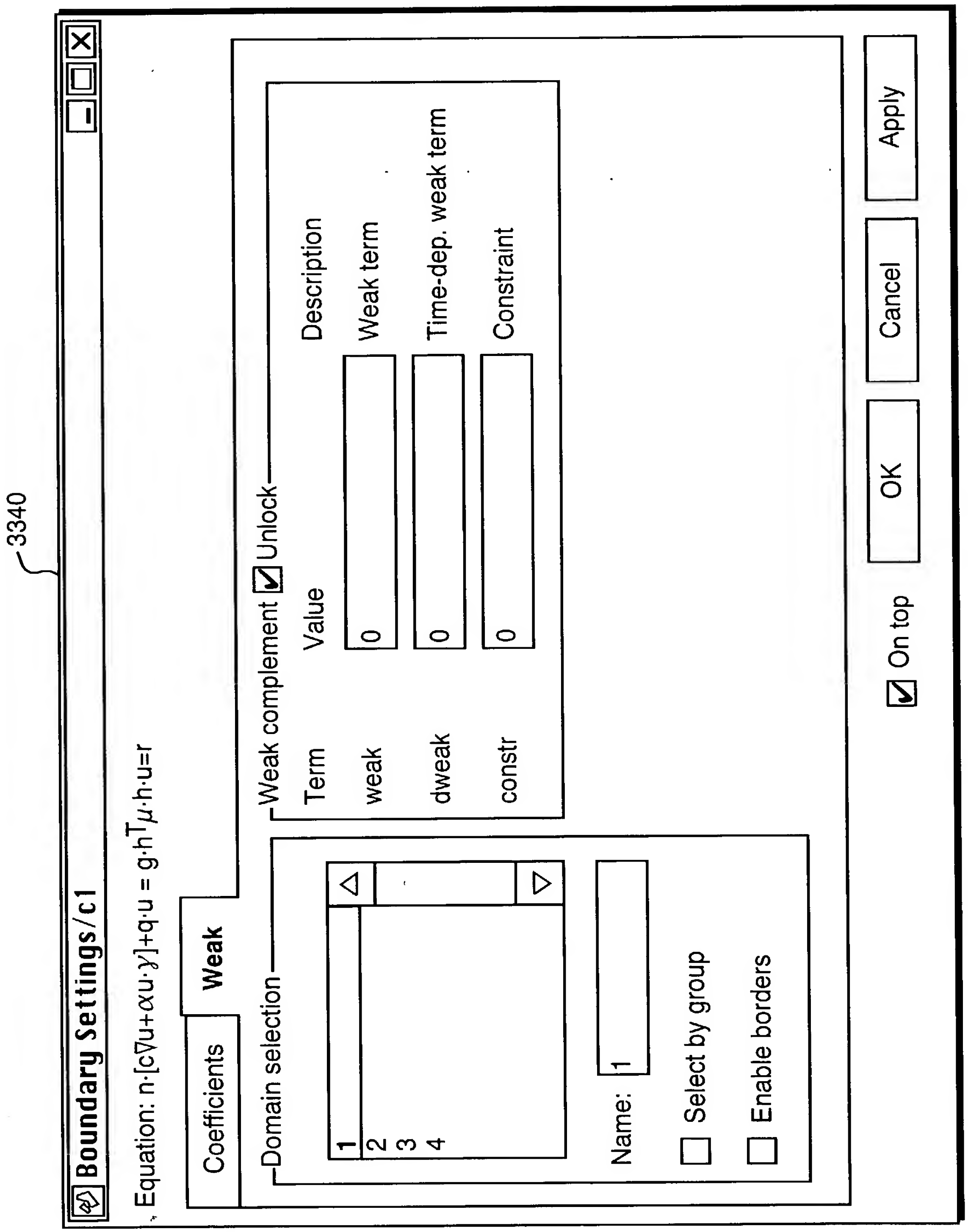

3340
Boundary Settings/c1
Equation: n·[c∇u+αu·γ]+q·u = g·h^{T}μ·h·u=r
Coefficients
Weak
Domain selection
1
2
3
4
Name: 1
Select by group
Enable borders
Weak complement
Unlock
Term
Value
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
On top
OK
Cancel
Apply

FIG. 70

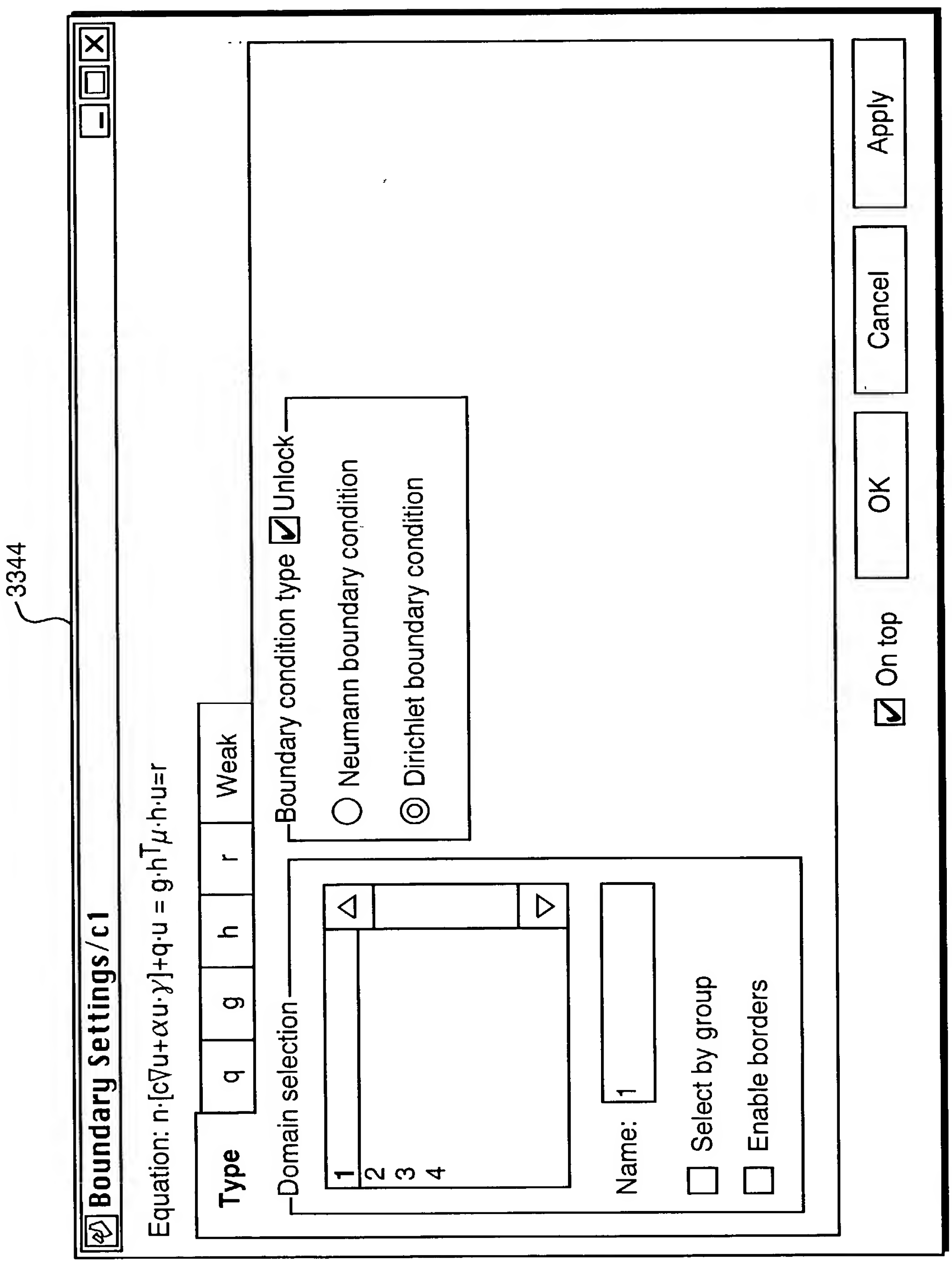

3344
Boundary Settings/c1
Equation: n·[c∇u+αu·γ]+q·u = g·h^{T}μ·h·u=r
Type
q
g
h
r
Weak
Domain selection
1
2
3
4
Name:
1
Select by group
Enable borders
Boundary condition type
Unlock
Neumann boundary condition
Dirichlet boundary condition
On top
OK
Cancel
Apply

FIG. 71

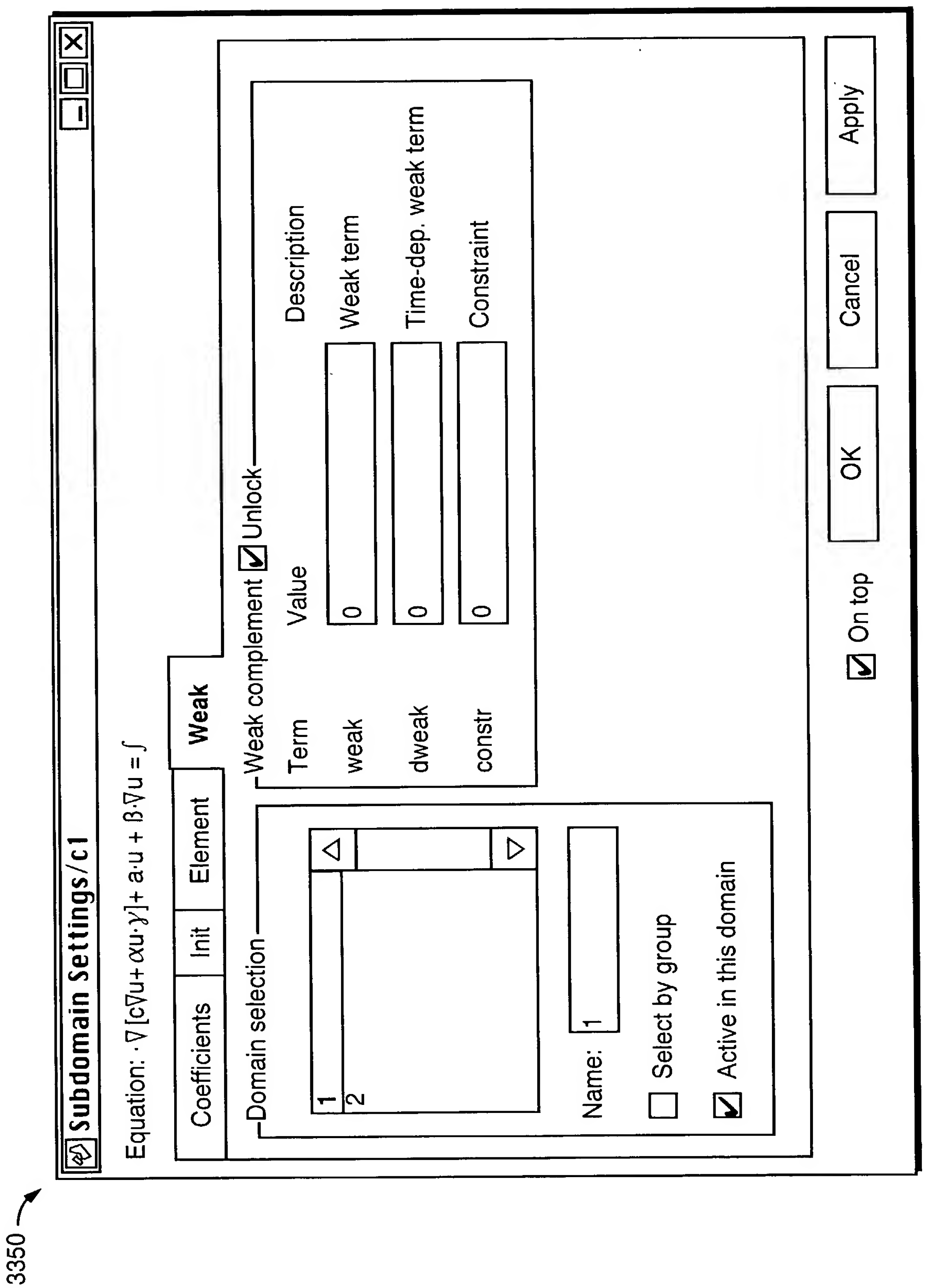

3350
Subdomain Settings/c1
Equation: $\cdot\nabla[c\nabla u+\alpha u\cdot\gamma]+a\cdot u+\beta\cdot\nabla u=f$
Coefficients
Init
Element
Weak
Domain selection
1
2
Name:
1
Select by group
Active in this domain
Weak complement
Unlock
Term
Value
Description
weak
0
Weak term
dweak
0
Time-dep. weak term
constr
0
Constraint
On top
OK
Cancel
Apply

FIG. 72

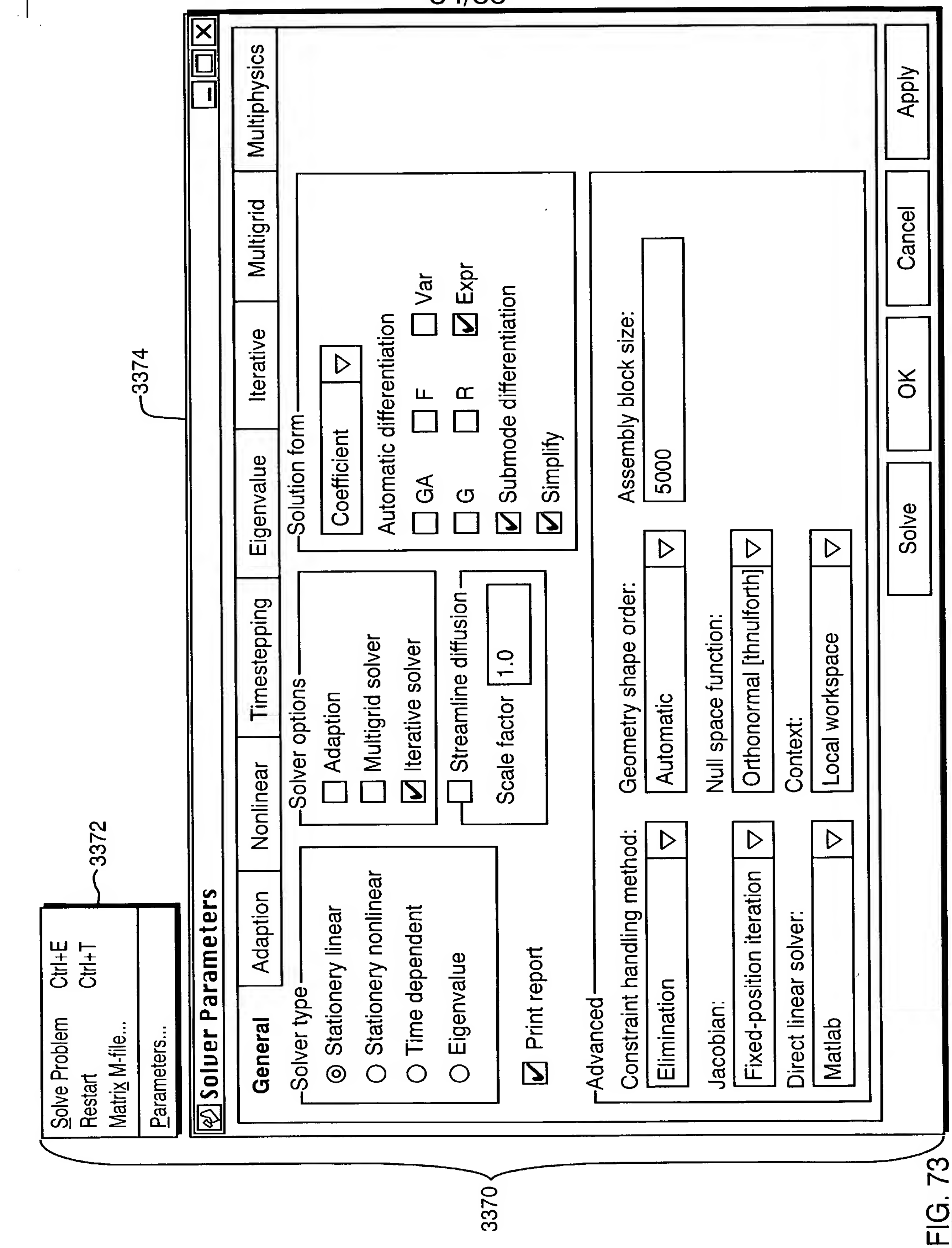

3370
3372
3374
Solve Problem Ctrl+E
Restart Ctrl+T
Matrix M-file...
Parameters...
Solver Parameters
General
Adaption
Nonlinear
Timestepping
Eigenvalue
Iterative
Multigrid
Multiphysics
Solver type
Stationery linear
Stationery nonlinear
Time dependent
Eigenvalue
Print report
Solver options
Adaption
Multigrid solver
Iterative solver
Streamline diffusion
Scale factor
1.0
Solution form
Coefficient
Automatic differentiation
GA
F
Var
G
R
Expr
Submode differentiation
Simplify
Advanced
Constraint handling method:
Elimination
Geometry shape order:
Automatic
Assembly block size:
5000
Jacobian:
Fixed-position iteration
Null space function:
Orthonormal [thnulforth]
Direct linear solver:
Matlab
Context:
Local workspace
Solve
OK
Cancel
Apply

FIG. 73

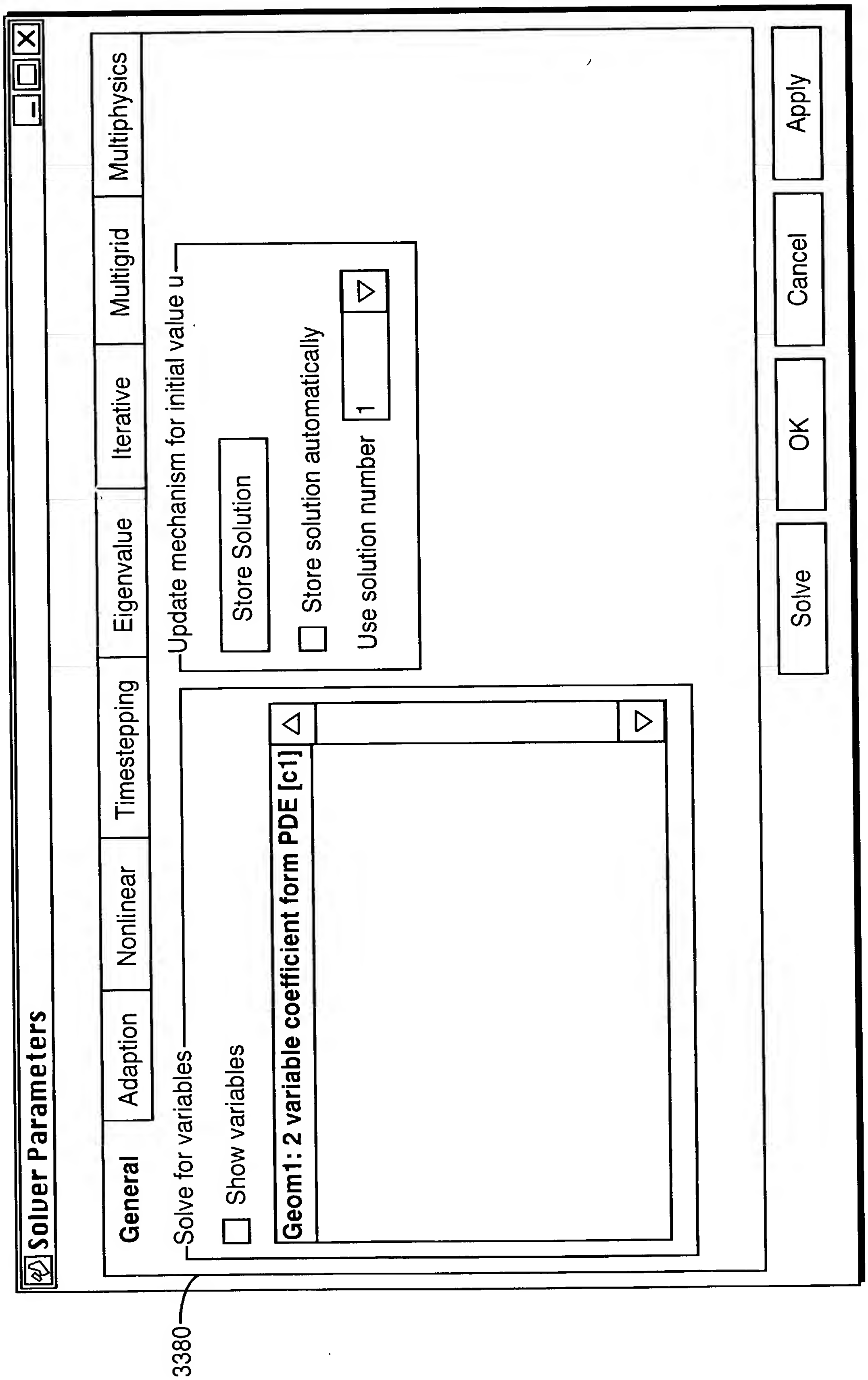

Solver Parameters
General
Adaption
Nonlinear
Timestepping
Eigenvalue
Iterative
Multigrid
Multiphysics
Solve for variables
Show variables
Geom1: 2 variable coefficient form PDE [c1]
Update mechanism for initial value u
Store Solution
Store solution automatically
Use solution number
1
Solve
OK
Cancel
Apply
3380

FIG. 74

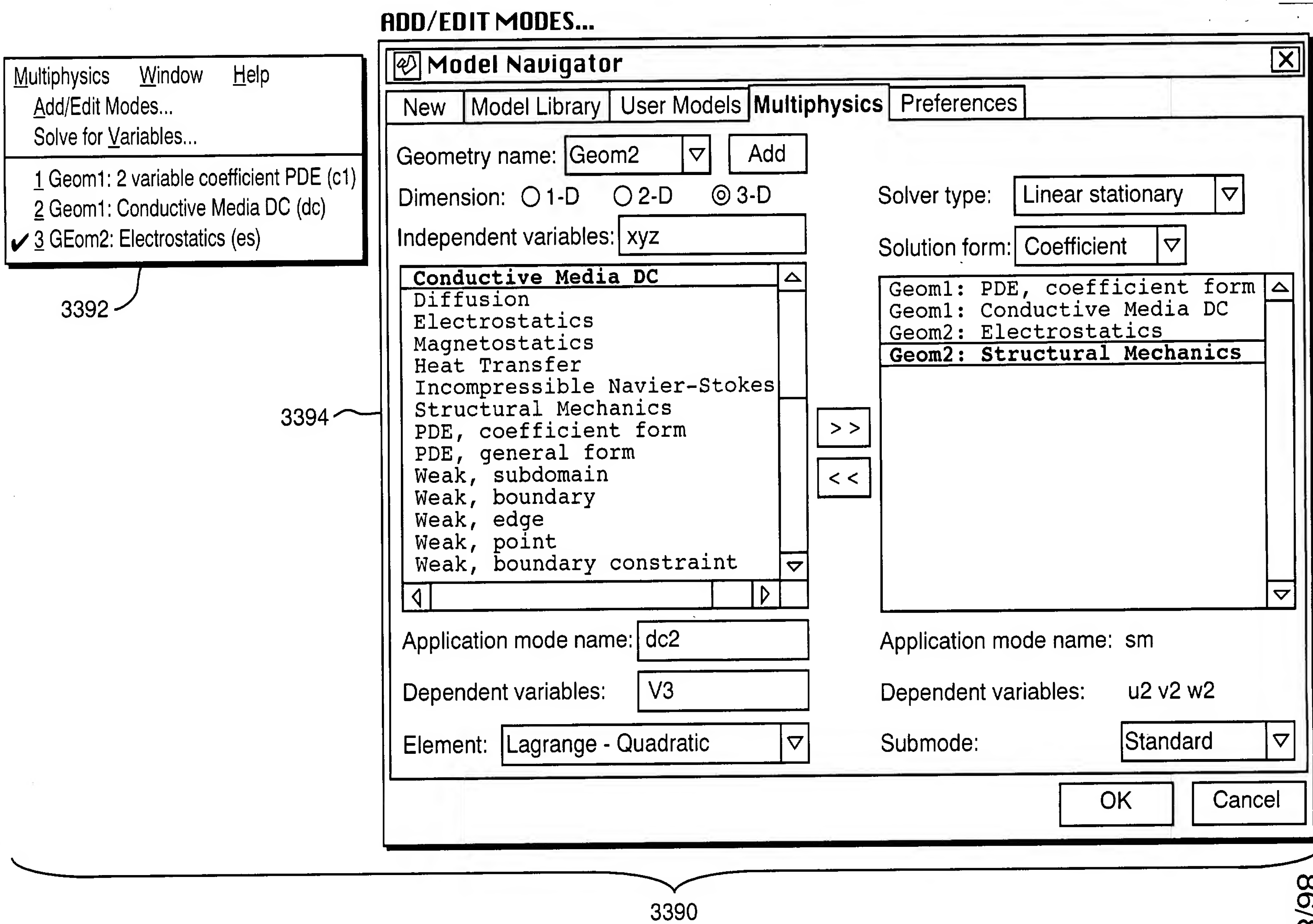

ADD/EDIT MODES...
Multiphysics
Window
Help
Add/Edit Modes...
Solve for Variables...
1 Geom1: 2 variable coefficient PDE (c1)
2 Geom1: Conductive Media DC (dc)
3 GEom2: Electrostatics (es)
3392
3394
Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Geometry name:
Geom2
Add
Dimension:
1-D
2-D
3-D
Independent variables:
xyz
Solver type:
Linear stationary
Solution form:
Coefficient
Conductive Media DC
Diffusion
Electrostatics
Magnetostatics
Heat Transfer
Incompressible Navier-Stokes
Structural Mechanics
PDE, coefficient form
PDE, general form
Weak, subdomain
Weak, boundary
Weak, edge
Weak, point
Weak, boundary constraint
> >
< <
Geom1: PDE, coefficient form
Geom1: Conductive Media DC
Geom2: Electrostatics
Geom2: Structural Mechanics
Application mode name:
dc2
Dependent variables:
V3
Element:
Lagrange - Quadratic
Application mode name: sm
Dependent variables: u2 v2 w2
Submode:
Standard
OK
Cancel
3390

FIG. 75